APR 17

THE JOURNAL of the Acoustical Society of America

VOL. 13 NO. 4

APRIL, 1942

Published for the

ACOUSTICAL SOCIETY OF AMERICA

by the

AMERICAN INSTITUTE OF PHYSICS

Lancaster, Pa., and New York, N. Y.

ACOUSTICAL SOCIETY OF AMERICA

FOUNDED 1929

OFFICERS

E. C. WENTE, *President*
Bell Telephone Laboratories
New York, New York

C. R. HANNA, *Vice President*
Westinghouse Electric
& Mfg. Company
East Pittsburgh, Pennsylvania

WALLACE WATERFALL, *Secretary*
The Celotex Corporation
Chicago, Illinois

LONSDALE GREEN, JR., *Treasurer*
Acoustical Construction Corporation
New York, New York

F. A. FIRESTONE, *Editor*
University of Michigan
Ann Arbor, Michigan

EXECUTIVE COUNCIL

H. S. KNOWLES
Jensen Radio Mfg. Company
River Forest, Illinois

ROBERT M. MORRIS
National Broadcasting Company
New York, New York

BENJAMIN OLNEY
Stromberg-Carlson Telephone Mfg. Co.
Rochester, New York

L. J. SIVIAN
Bell Telephone Laboratories, Inc.
New York, New York

W. F. SNYDER
National Bureau of Standards
Washington, D. C.

ROBERT W. YOUNG
C. G. Conn, Ltd.
Elkhart, Indiana

The officers are also members of the Executive Council

EDITORIAL BOARD

F. A. FIRESTONE, *Editor*

HARVEY FLETCHER
V. O. KNUDSEN
H. F. OLSON
WALLACE WATERFALL
E. C. WENTE

All communications concerning papers to be published should be addressed to the Editor, [illegible]

All communications concerning purchase or subscriptions should be addressed to the Publication Committee, Department of Physics, [illegible]

Changes of address should be addressed to the Publication Manager.

The Journal of the Acoustical Society of America is published quarterly at Lancaster, Pennsylvania.

Entered as second-class matter at the Post Office at Lancaster, Pennsylvania.

Copyright, 1943, by the Acoustical Society of America.

THE JOURNAL of the Acoustical Society of America

• CONTENTS •

Measurement of Flow Resistance of Porous Acoustic Materials . . . . . Richard L. Brown and Richard H. Bolt 337

Acoustic Filtration in Parallel Conduit Structures . . . . . L. W. Labaw 345

Acoustic Filtration by Membranes . . . . . L. W. Labaw 353

Analyzer for Sub-Audible Frequencies . . . . . H. H. Scott 360

Relation of Audiogram Measurements to Hearing Aid Characteristics Based on Commercial Experience . . . . . Fred W. Kranz and Carl E. Rudiger 363

Dynamic Auditory Localization 1. The Binaural Intensity Disparity Limen . Adelbert Ford 367

Method for Measuring the Percentage of Capacity for Hearing Speech . . . . . Edmund Prince Fowler 373

Experiments on the Pellet-Type of Artificial Drum . . . . . Karl Lowy 383

Change of Phase Caused by Impedance Deafness . . . . . Karl Lowy 389

Erratum: The Correlation Between Elastic Deformation and Vertical Forces in Lateral Recording . . . . . S. J. Begun and T. E. Lynch 392

Acoustical Society News 393

Current Publications on Acoustics

- Book Reviews 395
- References to Contemporary Papers on Acoustics 395
- Review of Acoustical Patents . . . . . Herbert A. Erf 399

Index to Volume 13. How to Use This Index. Classification of Subjects 411

Author Index to Volume 13 413

Analytic Subject Index to Volume 13 416

Table of Contents to Volume 13 iii

Vol. 13 APRIL, 1942 No. 4

THE JOURNAL
OF THE
ACOUSTICAL SOCIETY OF AMERICA

Volume 13 Number 4

APRIL • 1942

The Measurement of Flow Resistance of Porous Acoustic Materials*

RICHARD L. BROWN, *Eastman Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts*
AND
RICHARD H. BOLT, *Physics Department, University of Illinois, Urbana, Illinois*
(Received February 10, 1942)

The flow resistance is one of the three physical parameters of a uniform, rigid, porous material which completely determine its acoustic behavior; for more complicated materials and sound absorbing structures the flow resistance gives at least some acoustic information. The *specific flow resistivity* or flow resistance per unit cube is given by the equation $r=pAt/Vl$, in which p is the pressure drop in dynes per cm² across the thickness l cm of a sample of area A cm² when a volume V cc of air flows steadily through the sample in a time t sec. An accurate method has been developed for obtaining r by direct measurements of the quantities p, A, t, V, and l. Using this method flow resistance measurements have been made on twenty-four materials over a wide range of velocities. The measurements show that for nearly all materials there is a variation of flow resistance with velocity. For most materials the resistivity is constant below 0.1 cm per sec. but increases considerably at higher velocities. It is shown that previously described comparison methods, which have the advantages of simplicity and speed, might yield results in serious error unless certain suggested precautions are observed. As indicated previously, a direct correlation is found between the steady state flow resistance values and the resistive component of acoustic impedance for several materials. Analysis of the data also yields additional information bearing on the basic physical processes involved in the absorption of sound in these materials. In addition, the measurement of flow resistance has practical applications, such as the rapid routine checking of uniformity of samples of porous materials.

FLOW RESISTANCE

THE flow resistance of a porous substance is defined as the ratio between the pressure difference across a sample and the velocity of flow of air through that sample. This is quite analogous to the definition of electrical resistance as the ratio between voltage drop and current. The *specific flow resistivity* of a porous substance is defined as the flow resistance per unit cube. Let p be the pressure difference in dynes per cm² across a sample of thickness l cm and cross-sectional area A cm²; let V be the total volume of air flowing through the sample in a time t, then (V/t) is the volume velocity in cc per sec. The specific flow resistivity r is given by

$$r=\frac{pA}{(V/t)l} \text{ gram cm}^{-3} \text{ sec.}^{-1}. \qquad (1)$$

In much acoustical work it is more convenient to deal with the non-dimensional ratio of flow resistance per unit area (i.e., rl) to the characteristic resistance of air, ρc. Since for air $\rho c \backsimeq 42$ c.g.s. units, this *flow resistance ratio* for a given

* Presented in part at the twenty-fourth meeting of the Acoustical Society of America, Chicago, Illinois, November 15–16, 1940. Abs. 31, J. Acous. Soc. Am. 12, 475 (1941).

sample is given by

$$rl/\rho c = pA/42(V/t) \text{ (non-dimensional).} \quad (2)$$

The flow resistance is of interest in connection with impedance theory.[1] For some materials the flow resistance, which is a steady flow or d.c. resistance, is equal to the a.c. resistance R, which is the real part of the acoustic impedance.* For other materials the a.c. resistance may depart widely from the d.c. value; but it appears likely that in such cases the departure gives a clue to the absorption mechanism. For example, if the resistance R is much less than the value computed from the d.c. flow resistance, it is probable that considerable energy enters the material by compressional vibration, or by flexure.

DIRECT MEASUREMENT OF FLOW RESISTANCE

The method used in the present work requires the direct measurement of the four quantities p, A, V, and t on the right-hand side of Eq. (2). This method, illustrated in Fig. 1(a), involves conventional physical measurements which are basically very simple. A steady flow of air is maintained through the sample by siphoning water from the large bottle D through the tube C and the stopcock S. For steady flow the water flowing out through C into the graduate in a given time is replaced by an equal volume of air flowing through the sample and tube B. The pressure difference across the sample is measured by the manometer connected to the sample holder by tube A. In order to obtain results of sufficient accuracy and to take measurements in the velocity range which is of significance for acoustics, considerable care must be exercised in a number of small details. The problems involved may be classified under four headings as follows:

1. Mounting of the sample.
2. Maintenance of a steady flow of air through the sample.
3. Measurement of rate of flow of air.
4. Measurement of pressure difference across the sample.

1. Method of Mounting the Sample

In earlier work by Gemant, Rettinger, and others,[2] the sample was usually clamped between two rings of rubber, or some other soft material, and the outer edge of the sample was coated with paraffin to prevent undesired flow of air past the edges. The clamping may, however, introduce an unnatural strain in the material, particularly if it is soft or spongy. Such strain would probably alter the resistance properties. Sealing the edges with paraffin introduces an uncertainty as to the exact boundary of the cross-sectional area. Furthermore, the paraffin while in liquid state may penetrate into the pores of the material, thereby reducing the total air volume in the material.

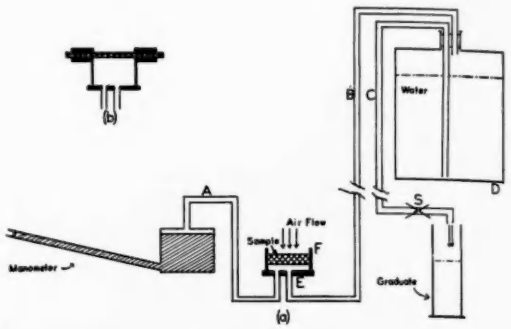


FIG. 1. Apparatus for the direct measurement of flow resistance of acoustical materials.

A suitable way to mount usual acoustic materials is to fit a disk of the material into a cylindrical container. One end of this cylinder is fitted with a cap with two tubes; one to be inserted into the air stream circuit, and the other to be connected with the pressure manometer. In one arrangement the cap in which the two tubes terminate is a flat plate mounted face upward, as shown in Fig. 1(a). The cylindrical sample holder is set on the plate and the joint sealed with "Grippit" or rubber cement, giving a quickly removable seal.

The sample must fit very accurately, since air leaks between the sample and the walls of the container introduce a large error. A good procedure is to use a sample container with a very slight conical taper. The sample is entered in the larger end and forced along the tube to a snug fit by means of a plunger. This method automatically adjusts for small variations in sample diameter. Samples of thin materials, such as Monk's cloth, are most conveniently mounted by

[1] P. M. Morse, R. H. Bolt, and R. L. Brown, "Acoustic impedance and sound absorption," J. Acous. Soc. Am. **12**, 217 (1940).

* For a thin material with rigid backing the theory predicts $R=(rl)/3$; for a thin material spaced $\lambda/4$ from a wall $R=rl$. See reference 1.

[2] A. Gemant, Sitz Preuss. Acad. wiss. Phys.-Math. Klasse, p. 579 (1933); M. Rettiner, J. Acous. Soc. Am. **6**, 188 (1935); A. Gemant, J. App. Phys. **12**, 729 (1941).

clamping them between flanges on the end of a short tube, as shown in Fig. 1(b). In all cases the separation between the sample and the air stream and manometer connections must be great enough so that the velocity will be uniform over the sample face.

The sample area chosen should be large enough to be truly representative of the average character of the material. This is reasonably well fulfilled by a three-inch diameter disk for fine grained homogeneous materials; but this size is too small for non-homogeneous materials with fissured surfaces.

2. Maintenance of Steady Flow of Air

The requirements on the air flow are that it be extremely steady, accurately adjustable, and that it can be made very slow. The procedure adopted is to siphon water at a controlled rate from a sealed container mounted at a considerable height above an outlet valve, allowing the air which displaces the water in the container to pass first through the sample. The container may be a large bottle or carboy mounted near the ceiling; the bottle is filled by the same tube used for siphoning. The valve allows a very precise control of the water flow. The slowest flow used has been about 0.1 cc/sec., and the fastest convenient with the present arrangement is about 200 cc/sec. For slower rates of flow the pressure drifts; faster rates of flow change the head of water appreciably during a measurement.

For a volume flow of 0.2 cc/sec. the velocity through a 3-inch diameter sample corresponds to the particle velocity in a free progressive sound wave in air of about 80-db intensity level. The slowest rates of flow used are, then, within the acoustic range.

3. Measurement of Rate of Flow of Air

The method of obtaining the air flow outlined above allows direct measurement of the rate of flow. A sample of water from the outlet is collected for a convenient length of time and the volume of water and the length of time are measured. Water volumes from 20 cc to 2000 cc, and times from 5 sec. to 5 min. have been used. In general, these quantities are chosen so that the experimental error in the measurement of (V/t) is about one-half of one percent.

The only assumption involved in this method is that the rate of efflux of water equals the rate of flow of air through the sample. This seems to be a reasonable assumption providing a steady state has been reached, and providing there are no marked variations in temperature, humidity, or air composition during the measurement. These conditions can be well satisfied, although for very low rates of flow it may take several minutes for equilibrium to be reached.

4. Measurement of Pressure Difference Across Sample

The measurement of pressure for low flow velocities is usually the limiting factor in the precision of flow resistance values. Over a wide range of pressures, that is, from 50 to 7500 dynes/cm^2, laboratory-made or commercial slant manometers‡ have proved satisfactory.

Since for many materials the flow resistance varies with the flow velocity, and therefore with the pressure difference (Eq. (1)), it is desirable to obtain measurements of resistance for a given sample over a wide range of pressures. In one case encountered, for example, the flow resistivity at 1 in. of water was approximately twice the value obtained at 0.01 in. The latter value should correspond more closely to the effective resistivity of the material in a sound field. For materials of such low flow resistance that a pressure drop of 50 dynes or so across a convenient size sample does not give a sufficiently small flow velocity, two or more layers of the material may be used in series in the cylindrical container. Such a "series" measurement gives, of course, the average flow resistance of the several samples rather than that of a single sample.

Slant manometers are not precise enough at pressures lower than about 0.02 in. In order to extend the range of measurement for a single sample down another order of magnitude, the Wahlen** gauge has been adapted to this work. This gauge is essentially a differential micro-

‡ Ellison Draft Gage Company, 214 West Kinzie Street, Chicago, Illinois. Two gauges which have been used are of the open type for wall mounting. One has a maximum range of 0.6 in. and the other a maximum of 3 in. of water.

** The Wahlen gauge. Reprinted from Bull. 120, Engineering Experiment Station, University of Illinois, Urbana, Illinois. The authors are indebted to Professor Albert E. Hershey, Department of Mechanical Engineering, University of Illinois, for information on the Wahlen gauge, and assistance in its use.

manometer and will measure a pressure difference as small as 0.0001 in. of water. It is direct reading down to a pressure of 0.001 in. and at this limit has adequate precision for flow resistance measurements. Using this gauge, data have been obtained with pressure differences as low as 2 dynes, with a maximum variation of 5 percent in the value of pressure over a large number of readings. Should lower pressures be desired, the Wahlen gauge could be made more sensitive by a factor of 10 by certain changes in its design. Adjusting and reading the Wahlen gauge is a comparatively rapid process; once a steady state flow of air has been attained it does not take much longer to read the Wahlen gauge than to read a simple slant manometer. To go to still lower pressures, one might use some sort of a traveling telescope, a type of measurement which is relatively slow and cumbersome, or other types of gauge suited for measurement of small pressure differences.[3]

TABLE I. Flow resistance values averaged from measurements on several samples. Individual samples of some of these materials exhibited variations as great as ±25 percent from the average value.

Material	Mfg. by:	Nominal thickness inches	r c.g.s. units	$rl/\rho c$ non-dimensional
Absorbex A (plain)	CC	1	3.0×10	1.8
Absorbex A (painted)	CC	1	5.6×10	3.4
Acoustex 30R	NGC	$\frac{5}{8}$	1.7×10	0.65
Acoustone D	USG	$\frac{11}{16}$	4.1×10^2	1.7×10
Akoustolith		$1\frac{1}{2}$	3.9×10	3.5
Celotex C-3	CC	$\frac{13}{16}$	2.8×10^2	1.4×10
Celotex M-1	CC	$\frac{5}{8}$	$*1.7\times10^3$	6.5×10
Celotex Tile	CC	$\frac{1}{2}$	$*1.7\times10^4$	5.0×10^2
Corkoustic B5	ACC	$1\frac{1}{2}$	$*2.5\times10^2$	2.3×10
Cork board (fine)		$1\frac{1}{2}$	$*5.5\times10$	5.0
Cork board (coarse)		2	1.2×10	1.5
Econacoustic	NGC	1	$*2.6\times10^2$	1.6×10
Fibretex	JM	1	3.3×10	2.0
Hair felt (matted)		$\frac{3}{4}$	2.2×10	0.9
Hair felt		$\frac{1}{2}$	1.5×10	0.45
Muffletone	CC	1	2.8×10^2	1.7×10
Permacoustic	JM	1	1.8×10^2	1.1×10
Quietone	USG	1	5.0×10^2	3.0×10
Spongecoustic	JM	$\frac{3}{4}$	1.2×10^2	5.4
Superfelt	JM	2	1.0×10	1.2
Temcoustic	ACC	$\frac{1}{2}$	2.0×10^2	6.0×10
Temcoustic 50	ACC	1	2.0×10^2	1.2×10^2
Birdseye cloth				0.3
Cigarette		$2\frac{3}{4}$	1.8×10	5.0
Cheesecloth				0.01
Cotton flannel				0.4

* These materials exhibit an appreciable slope down to the lowest values of velocity used. For these cases the value of r given is an *extrapolated* probable value, taken from data plotted as in Fig. 2. For all other materials listed, the value of r is a *limiting* value reached at low velocities.

Manufacturers: ACC Armstrong Cork Company; CC Celotex Corporation; JM Johns-Manville Sales Corporation; NGC National Gypsum Company; USG United States Gypsum Company.

[3] See, for example, *Modern Developments in Fluid Dynamics* (Oxford, 1938), edited by S. Goldstein, vol. 1, Chap. 6.

DISCUSSION OF MEASUREMENTS

The measurements of flow resistance on a number of common acoustic materials and some other porous materials are summarized in Table I; some of the details of data reduction are illustrated in Figs. 2 and 3 and discussed below. Measurements have been made on twenty-four materials, using a total of about two hundred samples; three observers have taken data independently, on three different sets of apparatus. A general observation on the results is that *flow resistance may vary widely* (± 25 percent) *for different samples of the same material, but can be measured accurately* (±2 percent) *by independently made measurements on a given sample.*

In Fig. 2 curves of the flow resistance ratio $rl/\rho c$ as a function of flow velocity for several acoustical materials are plotted in log-log coordinates. To keep the figure down to reasonable size for a wide range of flow resistance values only two decades have been drawn vertically. The approximate value of the flow resistance ratio and the location of the decimal point are shown in the parenthesis following the name of each material.

The first point of interest is that the *flow resistance varies with velocity* of the air flowing through the sample, for most of the materials and usually over a wide velocity range. This "slope" in flow resistance was not discussed by previous investigators,[2] although there is evidence that it was present in their results. It probably was masked by turbulence in the comparison capillary tube, as pointed out in a succeeding section. If measurements are made over a limited range of velocities, and if there is much spread in the data, the slope can easily be overlooked. Furthermore, if measurements are made at moderately high velocities only and these results are extrapolated to low velocities, the extrapolated value may be quite erroneous. As seen in Fig. 2, the resistance of some samples varies by factors of two or three. Very few of the twenty-four materials measured have shown no significant slope.

The next point of interest is that the *flow resistance levels off to a constant minimal value* at low velocities for most of the materials measured. It is assumed that the minimal value of flow resistance is the significant one, since in usual

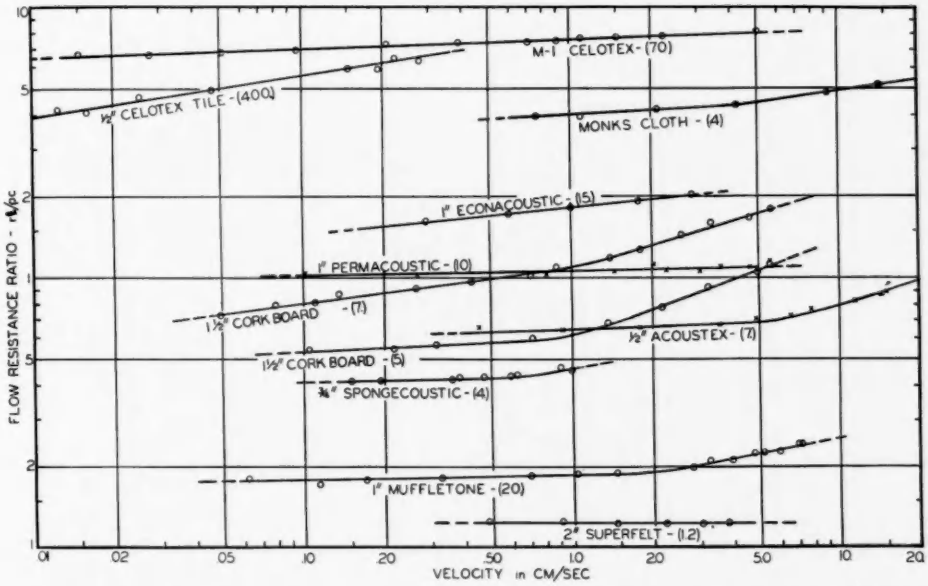

M-1 CELOTEX - (70)
½" CELOTEX TILE - (400)
MONKS CLOTH - (4)
1" ECONACOUSTIC - (15)
1" PERMACOUSTIC - (10)
1½" CORK BOARD - (7)
½" ACOUSTEX - (7)
1½" CORK BOARD - (5)
¾" SPONGECOUSTIC - (4)
1" MUFFLETONE - (20)
2" SUPERFELT - (1.2)
FLOW RESISTANCE RATIO - R/ρc
VELOCITY in CM/SEC

FIG. 2. Experimentally measured curves of flow resistance ratio as a function of average flow velocity for a number of acoustical materials. The approximate value of the flow resistance ratio and the location of the decimal point are given in parentheses following the name of each material.

acoustic conditions air velocities rarely exceed the lower velocity values shown in Fig. 2. Consider, for example, a sound pressure level of 100 db (20 dynes/cm^2) at the surface of the material. This is a reasonable value for impedance tube or reverberation measurements. For materials having impedance values ($z/\rho c$) from 2 to 20, the air particle velocity at the surface of the material ranges from .25 to .025 cm/sec. As seen in Fig. 2, the flow resistance of many materials is nearly constant over this velocity range.

These points are not clearly brought out when the data are plotted in linear coordinates, in which the curve is often *nearly* a straight line, but with a small, drooping tail extending over the first five percent or less of the curve. As an example, the data from Fig. 2 for one sample of corkboard and of Celotex M-1 are replotted on a linear scale in Fig. 3. In these curves the short drooping tail is very evident. It is obvious that a linear extrapolation of the main portion of the plots would not give the true minimal value of flow resistance. In some cases the low velocity droop may be missed entirely, particularly if the points at very low velocities are few or inaccurate.

The flow resistances listed in Table I are minimal values, except for the few materials marked (*) for which there was still an appreciable slope at the lowest velocities attained. In these cases an "extrapolation" was made, but this is a rather uncertain procedure since flow resistance curves do not have a unique shape.

The detailed nature of the flow resistance function is perhaps of more academic than practical interest. For purely laminar flow in cylindrical tubes, the relation between pressure and velocity is expressed by Poiseuille's law; in this case the flow resistance is a constant, independent of velocity. For completely turbulent flow, on the other hand, theory[4] predicts that flow resistance should be proportional to the first power of the

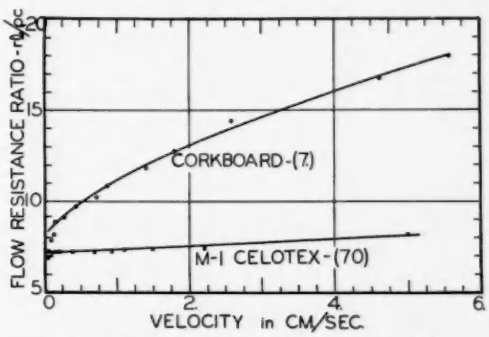


FIG. 3. Experimentally measured curves of flow resistance ratio for two acoustical materials. See caption of Fig. 2.

[4] See, for example, L. Prandtl, and O. G. Tietjens, *Fundamentals of Hydro- and Aerodynamics* (McGraw-Hill, 1934).

manometer and will measure a pressure difference as small as 0.0001 in. of water. It is direct reading down to a pressure of 0.001 in. and at this limit has adequate precision for flow resistance measurements. Using this gauge, data have been obtained with pressure differences as low as 2 dynes, with a maximum variation of 5 percent in the value of pressure over a large number of readings. Should lower pressures be desired, the Wahlen gauge could be made more sensitive by a factor of 10 by certain changes in its design. Adjusting and reading the Wahlen gauge is a comparatively rapid process; once a steady state flow of air has been attained it does not take much longer to read the Wahlen gauge than to read a simple slant manometer. To go to still lower pressures, one might use some sort of a traveling telescope, a type of measurement which is relatively slow and cumbersome, or other types of gauge suited for measurement of small pressure differences.[3]

TABLE I. Flow resistance values averaged from measurements on several samples. Individual samples of some of these materials exhibited variations as great as ±25 percent from the average value.

Material	Mfg. by:	Nominal thickness inches	r c.g.s. units	$rl/\rho c$ non-dimensional
Absorbex A (plain)	CC	1	3.0×10	1.8
Absorbex A (painted)	CC	1	5.6×10	3.4
Acoustex 30R	NGC	$\frac{5}{8}$	1.7×10	0.65
Acoustone D	USG	$\frac{11}{16}$	4.1×10^2	1.7×10
Akoustolith		$1\frac{1}{2}$	3.9×10	3.5
Celotex C-3	CC	$\frac{13}{16}$	2.8×10^2	1.4×10
Celotex M-1	CC	$\frac{5}{8}$	$*1.7\times10^3$	6.5×10
Celotex Tile	CC	$\frac{1}{2}$	$*1.7\times10^4$	5.0×10^2
Corkoustic B5	ACC	$1\frac{1}{2}$	$*2.5\times10^2$	2.3×10
Cork board (fine)		$1\frac{1}{2}$	$*5.5\times10$	5.0
Cork board (coarse)		2	1.2×10	1.5
Econacoustic	NGC	1	$*2.6\times10^2$	1.6×10
Fibretex	JM	1	3.3×10	2.0
Hair felt (matted)		$\frac{3}{4}$	2.2×10	0.9
Hair felt		$\frac{1}{2}$	1.5×10	0.45
Muffletone	CC	1	2.8×10^2	1.7×10
Permacoustic	JM	1	1.8×10^2	1.1×10
Quietone	USG	1	5.0×10^2	3.0×10
Spongecoustic	JM	$\frac{3}{4}$	1.2×10^2	5.4
Superfelt	JM	2	1.0×10	1.2
Temcoustic	ACC	$\frac{1}{2}$	2.0×10^2	6.0×10
Temcoustic 50	ACC	1	2.0×10^2	1.2×10^2
Birdseye cloth				0.3
Cigarette		$2\frac{3}{4}$	1.8×10	5.0
Cheesecloth				0.01
Cotton flannel				0.4

* These materials exhibit an appreciable slope down to the lowest values of velocity used. For these cases the value of r given is an *extrapolated* probable value, taken from data plotted as in Fig. 2. For all other materials listed, the value of r is a *limiting* value reached at low velocities.

Manufacturers: ACC Armstrong Cork Company; CC Celotex Corporation; JM Johns-Manville Sales Corporation; NGC National Gypsum Company; USG United States Gypsum Company.

[3] See, for example, *Modern Developments in Fluid Dynamics* (Oxford, 1938), edited by S. Goldstein, vol. 1, Chap. 6.

DISCUSSION OF MEASUREMENTS

The measurements of flow resistance on a number of common acoustic materials and some other porous materials are summarized in Table I; some of the details of data reduction are illustrated in Figs. 2 and 3 and discussed below. Measurements have been made on twenty-four materials, using a total of about two hundred samples; three observers have taken data independently, on three different sets of apparatus. A general observation on the results is that *flow resistance may vary widely* (± 25 percent) *for different samples of the same material, but can be measured accurately* (±2 percent) *by independently made measurements on a given sample.*

In Fig. 2 curves of the flow resistance ratio $rl/\rho c$ as a function of flow velocity for several acoustical materials are plotted in log-log coordinates. To keep the figure down to reasonable size for a wide range of flow resistance values only two decades have been drawn vertically. The approximate value of the flow resistance ratio and the location of the decimal point are shown in the parenthesis following the name of each material.

The first point of interest is that the *flow resistance varies with velocity* of the air flowing through the sample, for most of the materials and usually over a wide velocity range. This "slope" in flow resistance was not discussed by previous investigators,[2] although there is evidence that it was present in their results. It probably was masked by turbulence in the comparison capillary tube, as pointed out in a succeeding section. If measurements are made over a limited range of velocities, and if there is much spread in the data, the slope can easily be overlooked. Furthermore, if measurements are made at moderately high velocities only and these results are extrapolated to low velocities, the extrapolated value may be quite erroneous. As seen in Fig. 2, the resistance of some samples varies by factors of two or three. Very few of the twenty-four materials measured have shown no significant slope.

The next point of interest is that the *flow resistance levels off to a constant minimal value* at low velocities for most of the materials measured. It is assumed that the minimal value of flow resistance is the significant one, since in usual

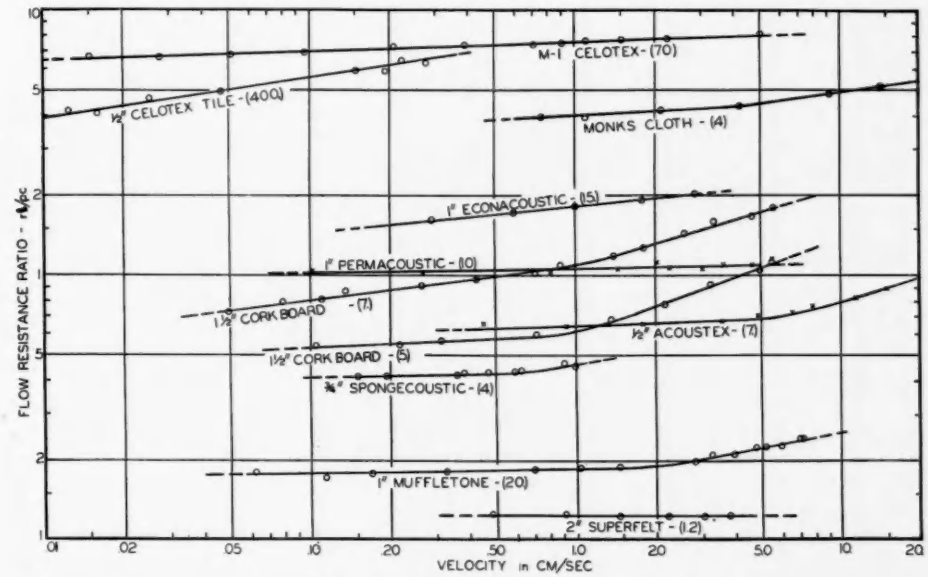


FIG. 2. Experimentally measured curves of flow resistance ratio as a function of average flow velocity for a number of acoustical materials. The approximate value of the flow resistance ratio and the location of the decimal point are given in parentheses following the name of each material.

acoustic conditions air velocities rarely exceed the lower velocity values shown in Fig. 2. Consider, for example, a sound pressure level of 100 db (20 dynes/cm²) at the surface of the material. This is a reasonable value for impedance tube or reverberation measurements. For materials having impedance values ($z/\rho c$) from 2 to 20, the air particle velocity at the surface of the material ranges from .25 to .025 cm/sec. As seen in Fig. 2, the flow resistance of many materials is nearly constant over this velocity range.

These points are not clearly brought out when the data are plotted in linear coordinates, in which the curve is often *nearly* a straight line, but with a small, drooping tail extending over the first five percent or less of the curve. As an example, the data from Fig. 2 for one sample of corkboard and of Celotex M-1 are replotted on a linear scale in Fig. 3. In these curves the short drooping tail is very evident. It is obvious that a linear extrapolation of the main portion of the plots would not give the true minimal value of flow resistance. In some cases the low velocity droop may be missed entirely, particularly if the points at very low velocities are few or inaccurate.

The flow resistances listed in Table I are minimal values, except for the few materials marked (*) for which there was still an appreciable slope at the lowest velocities attained. In these cases an "extrapolation" was made, but this is a rather uncertain procedure since flow resistance curves do not have a unique shape.

The detailed nature of the flow resistance function is perhaps of more academic than practical interest. For purely laminar flow in cylindrical tubes, the relation between pressure and velocity is expressed by Poiseuille's law; in this case the flow resistance is a constant, independent of velocity. For completely turbulent flow, on the other hand, theory[4] predicts that flow resistance should be proportional to the first power of the

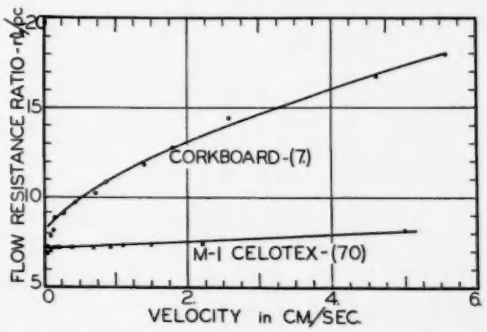


FIG. 3. Experimentally measured curves of flow resistance ratio for two acoustical materials. See caption of Fig. 2.

[4] See, for example, L. Prandtl, and O. G. Tietjens, *Fundamentals of Hydro- and Aerodynamics* (McGraw-Hill, 1934).

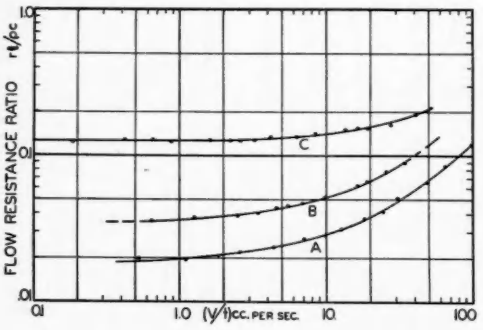


FIG. 4. Experimentally measured curves of flow resistance ratio for three capillary tubes as a function of rate of volume flow. The nominal bore of the capillaries is 0.15 cm, and their lengths are, respectively, tube *A* 4.14 cm, tube *B* 6.12 cm, and tube *C* 25.4 cm. The curves show the transition from laminar flow ($rl/\rho c$=const.) to turbulent flow ($rl/\rho c \sim$velocity).

velocity. Both types of flow are illustrated by measurements on capillary tubes discussed below, and plotted in Fig. 4. At low velocities curve *C* is flat; at high velocities curve *A* approaches a slope of unity in log-log coordinates. The transition region for these capillaries covers about two decades of velocity, and is a smooth and continuous curve. None of the flow resistance curves of acoustic materials in Fig. 2 reaches a slope as great as unity; the greatest slope, shown by corkboard, is approximately one-third. This indicates that complete turbulence is not reached in acoustic materials up to velocities of 10 cm/sec.

The direct correlation between steady state flow resistance values and the resistive component of acoustic impedance has been indicated previously.[1,5] The theoretical relationship is very simple for a rigidly backed homogeneous porous material at low frequencies, and for a thin and not too light, porous material spaced out approximately a quarter of a wave-length from a rigid backing wall.[6] For the first case the resistive component $R/\rho c$ of the acoustic impedance ratio $Z/\rho c = R/\rho c + jX/\rho c$, is approximately equal to $rl/3\rho c$, or one-third of the flow resistance ratio. In Table II are given experimentally measured values of these two quantities for seven materials. For four of the materials the agreement is quite satisfactory, particularly when one recalls that the impedance measurements are presumably for particular samples, while the flow resistance measurements are average values for a number of samples. It is interesting to note that in all cases where there is a sizable discrepancy between the static and dynamic values, the *dynamic value is lower*. This is to be expected if the material is light enough or compressible enough so that the action of the sound pressure is to move the material itself as well as to force air through its pores. This motion of the material may be represented in the equivalent circuit[6] by a branch which includes internal damping resistance in parallel with the flow resistance branch.

Impedance measurements of two hair felts spaced out approximately $\lambda/4$ from a rigid backing plate have been reported.[6] For this spacing of a porous material rigidly held in place the impedance is real and approximately equal to the d.c. measured flow resistance. For $\frac{1}{2}$ in. loose hair felt supported by expanded metal the dynamic value of $R/\rho c$ was 0.5 from 300 c.p.s. to 600 c.p.s. for an 8×8 in. sample. This compares with the average measured value of flow resistance 0.45. The corresponding dynamic value of $R/\rho c$ for a $\frac{3}{4}$ in. matted hair felt measured at 600 c.p.s. was 0.82, and is to be compared with the average d.c. value of 0.9. The agreement seems satisfactory for such a non-rigid and variable material as hair felt. The constriction of the flow through one surface by the expanded metal would tend to make the dynamic value high, and any motion of the felt would tend to make it low.

SECONDARY METHODS OF MEASUREMENT

While the direct method for the measurement of flow resistance is, in a sense, absolute, and can

TABLE II. Comparison between steady flow and dynamic values of resistance. For rigidly backed material the low frequency limiting value of the real part of the impedance ratio $R/\rho c$ is theoretically equal to $rl/3\rho c$.

Material	Steady flow $rl/3\rho c$	Dynamic* $R/\rho c$
Acoustone D	5.7	3.
Corkoustic B5	7.5	6.
Hair felt $\frac{3}{4}''$	.33	.27
Permacoustic	3.7	3.2
Quietone	10.	2.5
Spongecoustic	1.8	2.
Temcoustic	20.	13.

* The impedance of the hair felt was measured both with rigid backing ($R=rl/3$) and with approximately $\lambda/4$ air cavity backing ($R=rl$). The other impedance values are for rigid backing and were measured by Beranek [L. L. Beranek, J. Acous. Soc. Am. 12, 3 (1940)]. In cases where the value of $R/\rho c$ was not constant at low frequencies, the *minimum* value in the low frequency range was used, consistent with more recent data (see reference 5) and with theory (see reference 1).

[5] L. L. Beranek, J. Acous. Soc. Am. **13**, 248 (1942).
[6] R. H. Bolt and R. L. Brown, J. Acous. Soc. Am. **12**, 31 (1940).

be made as precise as desired, it is somewhat slow. A secondary method[2] which may be used as an auxiliary method for rapid, routine measurements requires drawing air through a capillary tube in series with the sample and measuring the pressure drops across the sample and across the capillary. The volume flow through a capillary is by Poiseuille's law

$$V/t = p_c \pi a^4 / l_c 8\eta, \qquad (3)$$

where p_c is the pressure drop across the capillary, a is its radius, l_c its length, and η is the viscosity of air. Since the volume flow is continuous through the capillary and the sample, we may equate (V/t) from Eq. (1) to Eq. (3) and get for the specific flow resistivity‡‡ of the sample in terms of the capillary constants:

$$r = (8\eta l_c A / \pi l a^4)(p/p_c). \qquad (4)$$

This method has been employed by earlier investigators,[2] but for the present study did not appear to be sufficiently accurate. For a precision study of flow resistance and its velocity dependence one cannot rely only upon geometrical measurements of a capillary and the assumption of laminar flow. Poiseuille's law of capillary flow holds only in the limit of very small velocities, and even in the Hagen-Poiseuille form with a correction term for kinetic energy,[4] breaks down when the velocity increases enough to cause turbulent rather than laminar flow.

Gemant's procedure in using this method was to plot the ratio p_c/p as a function of p_c in linear coordinates, and to use the value of p_c/p linearly extrapolated to $p_c=0$ in the calculation of resistance. Since in general the flow resistances of both the capillary and the sample vary non-linearly with p_c, the ratio of p_c/p is not exactly a linear function of p_c. For this reason the linear extrapolation of p_c/p to $p_c=0$ may be in serious error, in spite of the fact that any small portion of the curve is nearly a straight line.

The sort of difficulty one can encounter in the comparison method may be illustrated by working out an example, using values of flow resistance of a capillary tube and an acoustic material, as obtained by the direct method of measurement. Figure 4 gives the flow resistance ratio $(rl/\rho c)$ of three typical capillary tubes as a function of the rate of air flow (V/t). The capillaries were sections 25.4, 6.12, and 4.14 cm long, respectively, cut from a piece of glass tubing of nominal bore 0.15 cm. The capillaries were connected to the apparatus by rubber tubing, with no attempt to smooth out the entry to the capillary section. They were chosen so that the volume flows and pressure drops involved are comparable to those encountered in measuring acoustic materials. The curves in Fig. 4 indicate clearly that the flow resistances are far from constant in this range of pressure and rate of flow. In fact, they show the transition from laminar flow with a constant flow resistance, to turbulent flow with a flow resistance proportional to velocity. Longer capillary sections with smooth terminations would, of course, be expected to show laminar flow up to somewhat higher linear velocities or larger Reynolds numbers. Let us use capillary tube A in our hypothetical case. A sample of Muffletone is chosen, using the data from Fig. 2. Assume that a sample of 10-cm² area of this material is connected in series with capillary A, in the comparison method described above. From the data can be computed values of the pressure p across the sample and pressure p_c across the capillary which would be measured at any velocity. This information for a range of velocities is plotted in the manner of Gemant[2] as $(p_c/p)=f(p_c)$ in Fig. 5, curve A. Another example, using capillary C and a 2.0-cm² area sample of 1½ in. corkboard is plotted in curve B.

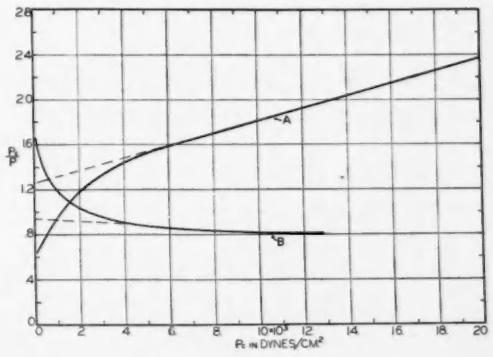


FIG. 5. Calculated curves for the ratio of pressure drop across a capillary to pressure drop across a sample of acoustical material when the two are connected in series for comparison measurement. The data are from curves of Figs. 2 and 4. Curve A is for a 10-cm² sample of Muffletone in series with capillary A. Curve B is for a 2-cm² sample of corkboard (7) in series with capillary C. The ratio p_c/p is plotted as a function of p_c after Gemant.

‡‡ It will be noted that by our definition flow resistance is independent of porosity, at variance with Gemant's definition.

Looking at Fig. 5, curve A, we see that if p_c were measured down only to 3000 or 4000 dynes/cm², the extrapolated value of p_c/p would be taken as about 1.3, whereas the lowest actual value of p_c/p on this curve is 0.6. In this case the minimal value would be very nearly 0.6, as the flow is laminar in both the capillary and the material at the lowest readings taken. In curve B, Fig. 5, the linear extrapolation from points above $p_c=3000$ is about 0.9, while the actual value, near $p_c=0$ is 1.7 or more. In this case the minimal value is not reached, since the flow in this material is turbulent over the entire measured range.

These hypothetical examples represent two extreme cases. In case A the flow in the comparison capillary is turbulent over most of the range and the flow in the sample is almost laminar (small slope in Fig. 2); in case B the flow in the capillary is laminar and the flow in the sample is turbulent (large slope in Fig. 2). In either case the extrapolated value of p_c/p, and hence the computed value of $rl/\rho c$ may be off by as much as a factor of 2 from the true limit as the velocity approaches zero. In cases involving intermediate degrees of turbulence in the sample or capillary, the error in extrapolation might be considerably less than for the extreme cases given here.

The above discussion does not imply that secondary methods are not useful. The comparison method of Gemant and Rettinger has the advantages of simplicity and speed; it can yield results with sufficient accuracy for most purposes, if the following precautions are observed.

(1) The comparison capillaries should be calibrated by direct measurements over the entire range used. This should be done in the actual set-up, since additional resistance and turbulence can be contributed by joints and connecting tubes.

(2) Measurements should be made at very low velocities in order to obtain flow resistance values valid at acoustical velocities. While this necessity has been pointed out,[2] quantitative limits have not been indicated previously. For most materials a linear flow velocity of 0.1 cm/sec. is low enough, though for a few (such as those marked (*) in Table I) turbulence is present at 0.01 cm/sec. In some cases, 1.0 or even 10 cm/sec. does not cause turbulence. The limit for each material should be determined independently before one can rely on comparison measurements on that material.

A simple method for making rapid measurements of flow resistance,[a] suitable for routine field tests of plaster and other materials, even after installation, has been described by Knudsen.[7] The flow resistance is determined by measuring the time required for a certain amount of air to be forced through the sample, using simply an air pump, a 5-gallon bottle, a U-tube manometer, and a funnel sealed against the acoustic material. The calibration is purely relative; one notes the number of seconds required for a given drop in pressure on a known sample, and compares the field tests with this. Knudsen points out that if such tests "are conducted intelligently, they will reveal pertinent information . . . " and that although these "tests are very crude, they are often of great value in ascertaining the approximate absorptivity of materials . . . "

CONCLUSION

In conclusion we see that there are two main aspects of flow resistance and its measurement. On the one hand, detailed and precise measurements are necessary for a basic study of absorption mechanisms and for correlation of acoustic impedance and sound absorption measurements with theory. On the other hand rapid, routine measurements on calibrated or comparison apparatus can assist in the development of new or modified sound absorbing structures, offering a convenient means of checking successive steps without going through impedance or absorption measurements. Such measurements can also be useful in the routine checking of materials in manufacture or field installation to maintain specified uniformity or tolerances between lots.

The authors are indebted to Professor P. M. Morse and Mr. J. R. Pellam of Massachusetts Institute of Technology for many helpful discussions and suggestions, and to Mr. E. L. Younker of the University of Illinois, who made some of the measurements.

[a] The word "porosity" has been used by Knudsen and others to describe the property measured by these methods. Following the definitions given in reference 1, we reserve "porosity" for the effective ratio of volume of free air in a material to the total volume of the material.

[7] V. O. Knudsen, *Architectural Acoustics* (John Wiley, New York, 1932).

Acoustic Filtration in Parallel Conduit Structures*

L. W. LABAW
Brown University, Providence, Rhode Island
(Received January 18, 1942)

The filtration characteristics of five Quincke-Herschel tubes in series were measured in three ways: (a) by observing the ratio of the squares of the excess pressures at the end and beginning of the filter when terminated by a closed and open finite ending; (b) by observing the phase difference between these two pressures for the two cases in (a); and (c) by observing the true power transmission ratio with the filter terminated by an effectively infinite line. The experimental results are plotted with the corresponding theoretical curves. The number of experimental peaks in the transmission regions in (a) and (c), and the positions of the attenuation bands agree with the predictions of the theory. The values of the curve minima in the transmission bands are in excellent agreement up to 5000 cycles. The change of phase over the filter was also found to correspond closely to the theory.

INTRODUCTION

THE research reported in this paper is intended as a confirmation of the theory presented in a previous article for the selective characteristics of a finite acoustic filter having Quincke-Herschel tubes as sections, terminated by a finite ending.[1] A filter with two types of finite endings was investigated and the agreement was gratifying enough to make work with the other types of finite endings described in the previous paper uninteresting relative to two further investigations. These are (1) change of phase over the finitely terminated filter, and (2) measurement of the true power transmission with an effectively infinite termination, in place of the ratio of the pressure amplitudes at the two ends of the filter with the finite terminus.

It may be recalled that the filtration characteristics of an acoustic structure having an infinite number of sections, neglecting dissipation, is given theoretically by the cosine of a complex angle, usually denoted by W, where $\cos W$ is a function of frequency and is always real.[2] The angle W is either all real or pure imaginary; when it is real there is transmission, and when it is imaginary there is attenuation. For the case considered in which the lengths of the two Quincke-Herschel tubes equal the length of the conduit between sections (or $l_1=l_2=2l$), the general equations for $D=\cos W$, and E given in Eqs. (8) and (9) of the theoretical paper,[1] reduce to

$$\left.\begin{aligned} D&=\cos^2 2kl-\frac{1}{2}\left(q+\frac{1}{q}\right)\sin^2 2kl \\ E&=\sin 2kl[\cos 2kl-q\sin^2 kl \\ &\qquad +(1/q)\cos^2 kl] \end{aligned}\right\}, \quad (1)$$

where $k=2\pi\nu/c$; $q=Z(Z_1+Z_2)/Z_1Z_2$; $Z_n=\rho_0 c/S_n$; c = sound velocity in air.

S_1 and S_2 are the areas of the two Quincke-Herschel tubes and S is the area of the connecting conduit. The selective properties and phase relations of the finite filter may be expressed by the quantities defined by Eq. (1), with the appropriate terminating impedances.

Figure 1 shows the actual filter used. It was made from copper tubing which was carefully bent to keep the area of cross section uniform. The three tubes were joined by a small box which was partially filled with solder to assure

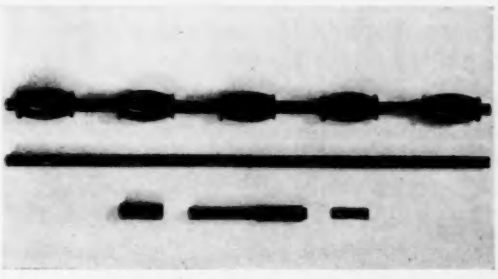


FIG. 1. Photograph of the filter and one of the microphones, and the conduit, with the connecting couplings, by which the filter was replaced.

* Presented at the Providence Meeting of the American Physical Society on June 20, 1941.
[1] L. W. Labaw, J. Acous. Soc. Am. **12**, 232 (1940).
[2] R. B. Lindsay, J. App. Phys. **9**, 615 (1938).

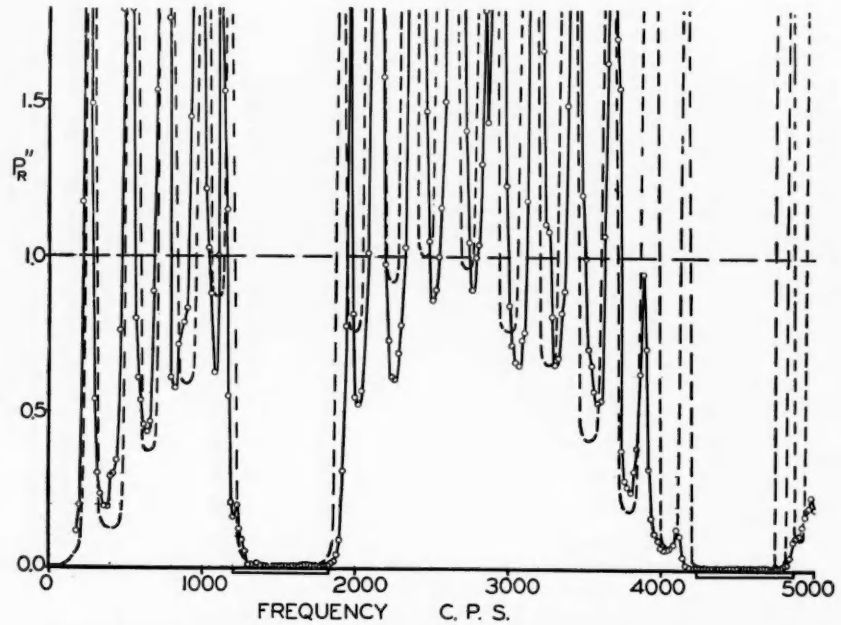


FIG. 2a. Theoretical and experimental curves for the ratios of the excess pressures squared at the two ends of the filter terminated by a finite open cylindrical conduit, for the frequency range 0 to 5000 cycles.

as nearly streamline flow as possible through the change in area. The dimensions of this equalization chamber were small compared to the lengths of the tubes. The radii of the tubes used were $r=0.58$ cm; $r_1=0.70$ cm; $r_2=0.40$ cm. The average axial length of the tubes was 5.6 cm.

The source of sound was a large Atlas speaker unit which was fed through a power amplifier (8 watts) by a General Radio low frequency oscillator which had been calibrated every 20 cycles from 0 to 10,000 cycles and had negligible frequency drift. The detector was a pressure sensitive Rochelle salt crystal microphone placed inside the tube with its length parallel to the tube axis. Its construction was similar to the small Brush sound cell, but with smaller crystal and outside dimensions and with internal support for the leads. The microphone contained two bimorph elements in parallel whose individual crystals were X-cut with edges making angles of 45° with the Y and Z crystal axes. The output of the microphone was passed through three stages of amplification; the first two had an approximate voltage gain of 100 times and the third one, 40 times. This voltage was then placed across the vertical deflecting plates of an RCA oscillograph having a three-inch screen with a sensitivity of 20 volts per inch. The crystal currents were thus of the order of 10^{-8} amp. which gave a linear relation between the crystal response and crystal activation. This was tested experimentally and found to be true.

There was always an air space of a few thousandths of an inch between the filter and the source to eliminate response from mechanically transmitted vibrations. The filter itself was mounted on a concrete pillar set in the ground, and insulated from the pillar by thick horse-hair felt. This eliminated nearly all the mechanical vibrations proceeding from the surroundings. The readings were taken from the oscillograph screen rather than an output meter, to have a constant check on the wave form, which the theory requires to be sinusoidal.

RATIO OF THE PRESSURES AT THE TWO ENDS OF THE FILTER

Since the curves computed in the previous paper giving the selective characteristics for finite filters with finite terminations were velocity curves, the equations given there must be slightly modified to predict pressure measurements. Instead of P_r' we will define a new ratio,

$$P_r''=|p_{n+1}|^2/|p_1|^2, \qquad (2)$$

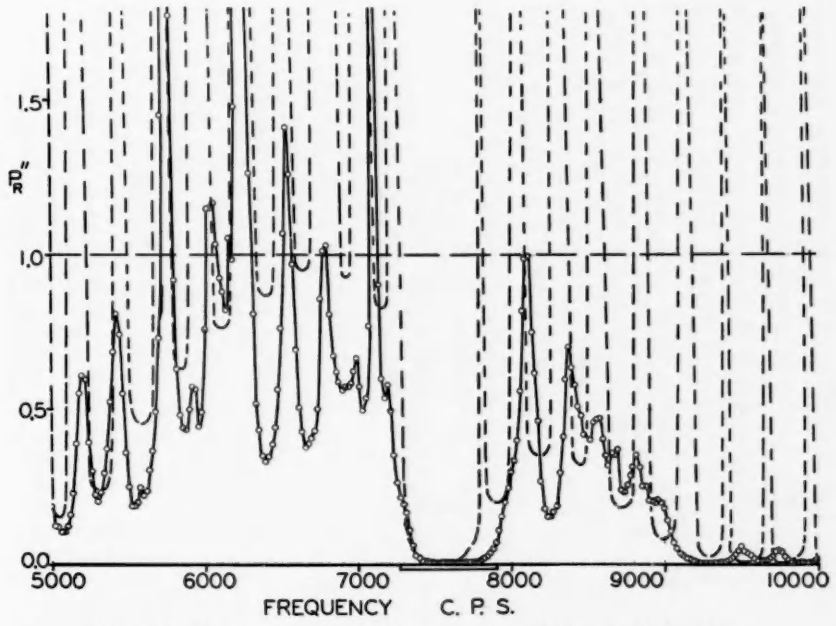


FIG. 2b. The same as Fig. 2a, for the region 5000 to 10,000 cycles.

where p_{n+1} is the excess pressure at the end of the last section and p_1 is that at the beginning of the first section. Going back to Eq. (11) of the theoretical paper[1] and remembering that from mathematical induction the subscript n and the coefficient of W (which is unity) may be interchanged, we have

$$P_r''=1\Big/\left|\cos nW+i\frac{Z}{Z_t}E\frac{\sin nW}{\sin W}\right|^2, \qquad (3)$$

where $Z_t=p_{n+1}/\dot{X}_{n+1}$ is the terminal impedance of the filter. If the filter is terminated by a cylindrical tube of area S and length l', then $Z_t=iZ\tan kl''$, where $l''=l'+S/c_0$ is the effective tube length[3] and c_0 is the conductivity of the opening. The ratio thus becomes for the open ending,

$$P_r''=1\Big/\left(\cos nW+\cot kl''E\frac{\sin nW}{\sin W}\right)^2. \qquad (4)$$

In order to get P_r'' experimentally, two microphones of the type described above were used. Either one could be connected to the amplifier by a switching device. The difference in sensitivities of the microphones was corrected for by reversing the flow of energy through the filter. Readings were taken in each direction, then the product of these two ratios gave the desired P_r''. Because of the temperature effect on the response of an X-cut crystal, this reversal of sound energy was made for each frequency within a short interval of time. This was accomplished by rotating the generator which was suspended from a counterbalanced beam through 180°, and having both ends of the filter of similar construction. The inner agreement among the three runs made indicated that the precautions taken in the measurements were adequate.

Figures 2a and 2b show the agreement between theory and experiment. There are no experimental values below 180 cycles because the wave form in this region was distorted for this particular arrangement. In the computation of the theoretical curve the value of the conductivity chosen was $c_0=1.91$. This value was found to bring the theoretical curve in closest agreement with the experimental one with regard to the depths of the minima. Rayleigh's theoretical value is $c_0=2.32$, while the value calculated by an empirical formula given by Robinson is $c_0=2.64$.[4] These values definitely did not give

[3] G. W. Stewart and R. B. Lindsay, *Acoustics* (New York, 1930), p. 150.

[4] N. W. Robinson, Proc. Phys. Soc. London **46**, 772 (1934).

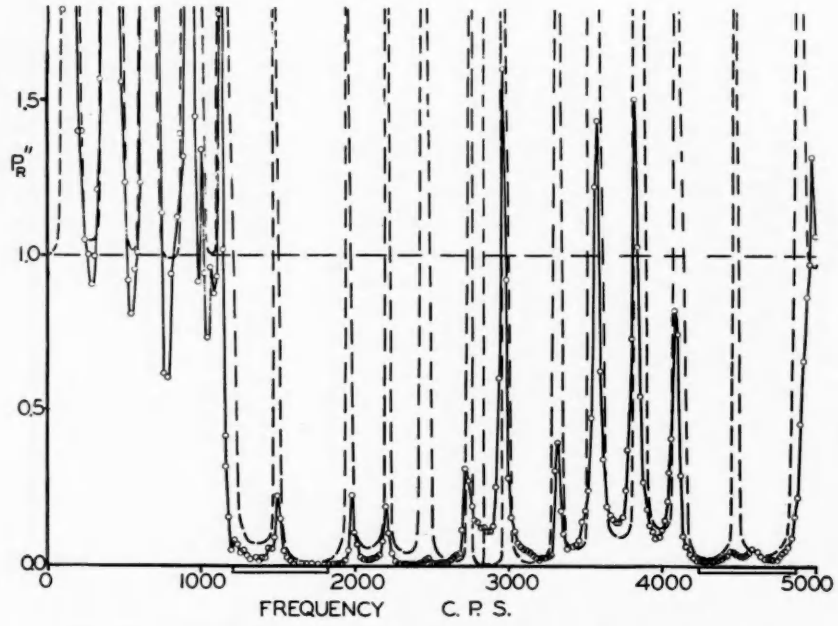


FIG. 3a. Comparison of theory and experiment for the square of the ratio of the excess pressures at the two ends of the filter terminated by a closed finite cylindrical tube, for the region 0 to 5000 cycles.

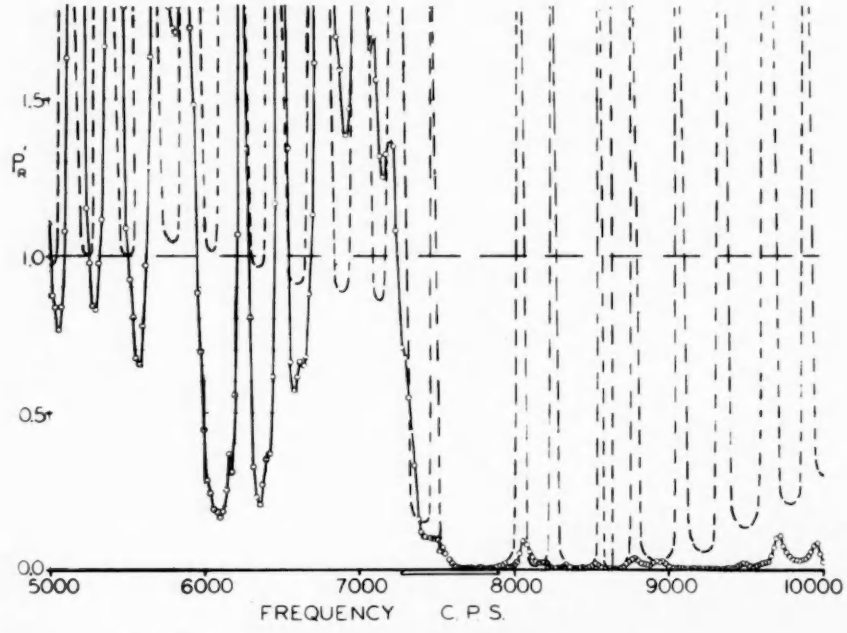


FIG. 3b. Same as Fig. 3a, for the region 5000 to 10,000 cycles.

good agreement. Robinson did not report the limiting case in which the hole diameter is equal to that of the tube so his empirical formula has not been tested for this case. The experimental peaks are not as high as the theory predicts because of the neglect of dissipation. At high frequencies the assumption that the diameter of the tube is small compared to the wave-length becomes invalid; however, the envelope of the curve is still favorable. The agreement is very

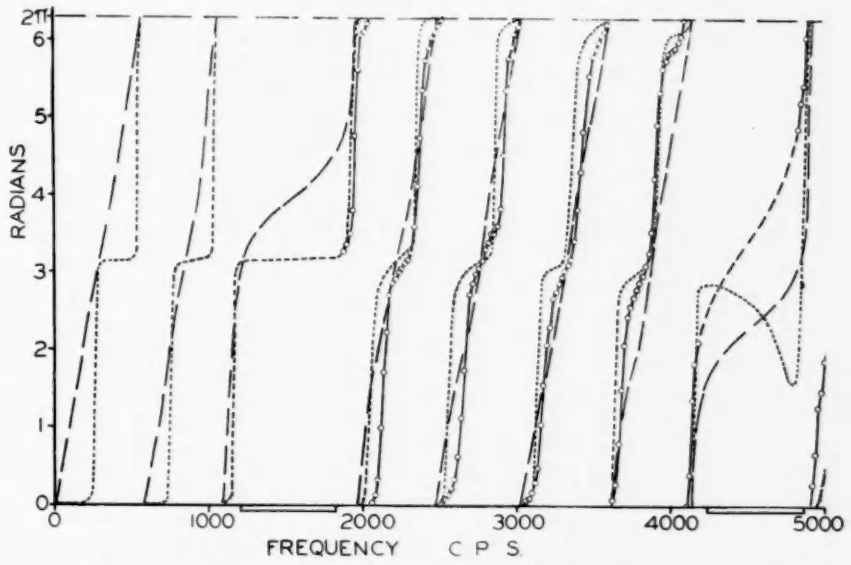


FIG. 4a. The phase difference between the pressures measured in Fig. 2, compared with two approximate theoretical curves, for the region 0 to 5000 cycles.

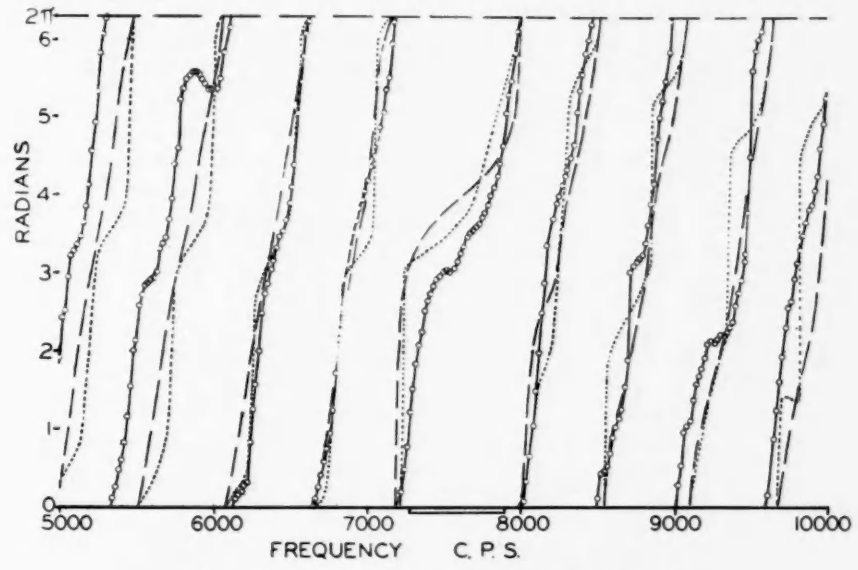


FIG. 4b. The same as Fig. 4a, for 5000 to 10,000 cycles.

good up to 5000 cycles. In the second region the slight disagreement may be due to the structural defects which become increasingly important for the shorter wave-lengths. The underlined portions of the abscissa indicate the attenuated region predicted for the equivalent infinite filter.

Figures 3a and 3b show the agreement between theory and experiment for a finite ending of the same dimensions as Figs. 2a and 2b, but with the end closed. This theoretical curve contains no uncertain constant such as conductivity and is given from Eq. (3) by,

$$P_r'' = \frac{1}{(\cos nW - \tan kl'E \sin nW/\sin W)^2}. \quad (5)$$

The method of measurement was the same as was used for the open end: the ending was

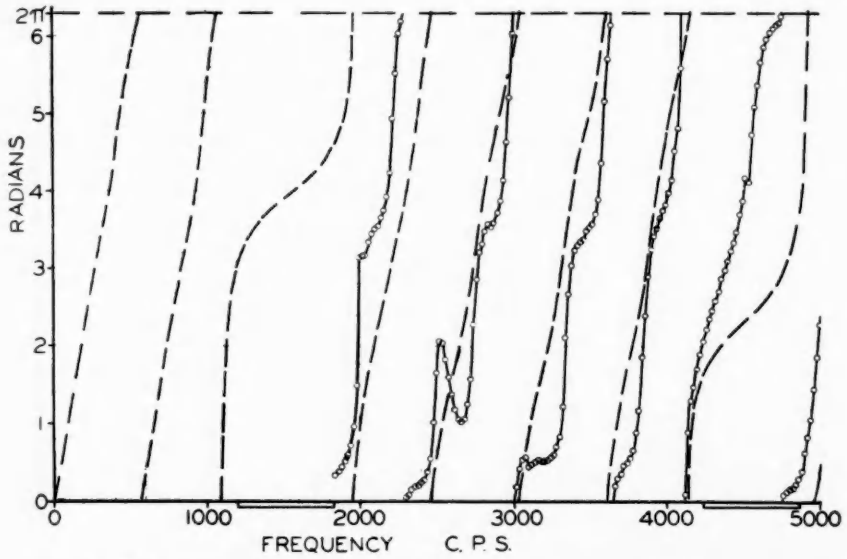


FIG. 5a. The phase difference between the pressures measured in Fig. 3, compared with the theory for the filter with no reflected wave due to the termination, for the lower frequency region studied.

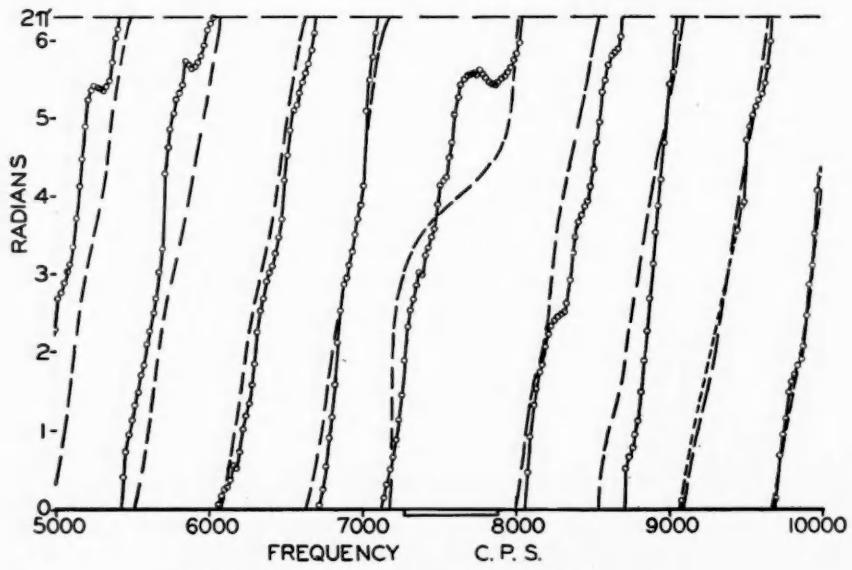


FIG. 5b. Similar to Fig. 5a, but for the upper region.

closed by a brass plate which was shifted from end to end as the sound energy was reversed. The theory assumes the terminating wall to be perfectly rigid; this was well realized considering the density differences. It is noted that the theory predicts one less peak here than for the open end case; the peaks are not high but they are all indicated. The experimental peaks in the attenuation bands are considered as a particularly good check on the theory. The values greater than $P_r''=1.8$ are not plotted but they reached 15 and 20 in some cases. These high values were around 5700 and 6800 cycles. The disagreement in the region from 5000 to 7500 cycles is again probably due to structural errors.

PHASE CHANGES OVER THE FILTER

Theoretically there is no phase change over the filter with the two types of finite endings

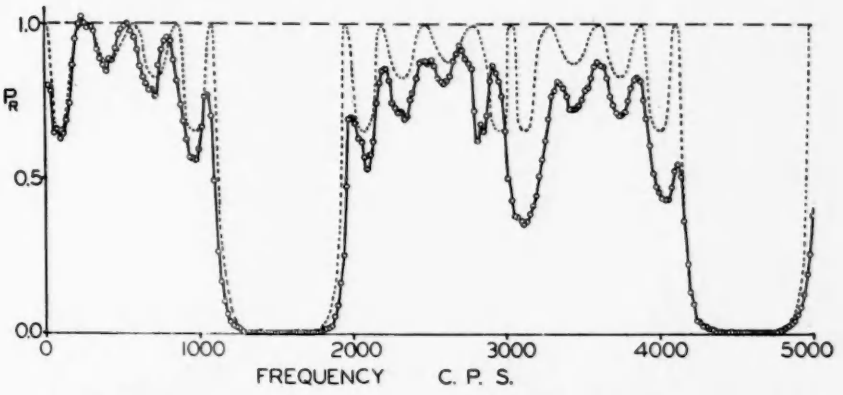


FIG. 6a. The agreement between theory and experiment for the true power transmission ratio for the filter terminated by an effectively infinite line, for the lower frequency region.

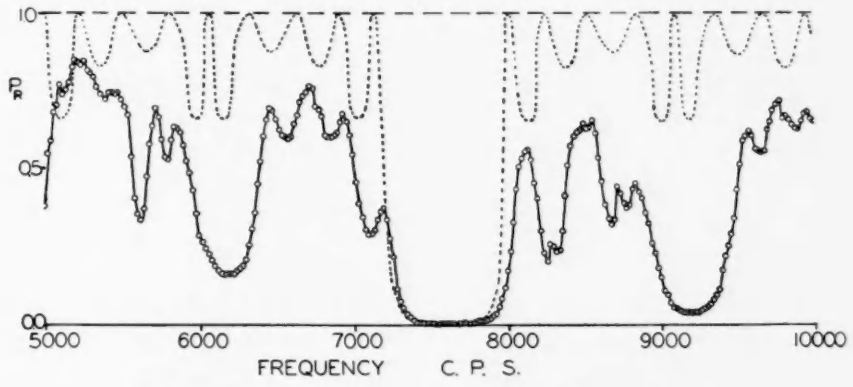


FIG. 6b. The same as in Fig. 6a, for the upper region studied.

just considered, unless dissipation is accounted for. By allowing for the dissipation due to radiation from the open end and making some simplifying approximations, the equation defining the phase angle between p_{n+1} and p_1 for the open finite ending takes the form,

$$\tan\theta=\frac{\dfrac{2\pi S}{c^2}\nu^2\csc^2 kl''}{\sin W/(E\tan nW)+\cot kl''}. \qquad (6)$$

This is the dotted curve plotted in Figs. 4a and 4b. With it are plotted the experimental values and also the phase change to be expected if the terminating length is effectively infinite.[5] The equation for this dashed curve is

$$\tan\theta'=E\tan nW/\sin W. \qquad (7)$$

[5] R. B. Lindsay, J. Acous. Soc. Am. **8**, 211 (1936).

Different amplifiers were used for the voltages of the two microphones. One of these voltages was put across the horizontal and the other across the vertical deflecting plates of the oscillograph. Since the amplifiers were identical, the phase change introduced by each was the same. By adjusting the amplitudes of the two signals by potentiometer arrangements preceding the amplifiers to have the horizontal and vertical deflections equal, the phase angle was obtained by measuring the axes of the ellipses formed. Below the first attenuation band, the crystal sensitivities were such that to get equal amplitudes of sufficient magnitude for accuracy, necessitated a violent excitation of the generator which distorted the wave form. This region could be studied with different microphones, which, however, would probably have undesirable resonances in the higher frequency region.

The experimental results show that the

measured angle is between θ and θ'. Two of the 360° phase changes are displaced (around 5000 and 6000 cycles) from the theory, but the higher range is again in good agreement. The points in the first two attenuation bands could not be obtained for the reason mentioned above.

Figures 5a and 5b show the results of measurements of the same type for the closed ending plotted with the curve for θ'. The dissipation in the filter itself and in the ending is sufficient to give a phase change over the filter. Examination of the theory shows, that if there is any imaginary part to the ratio p_{n+1} to p_1, the phase change is approximately that for the filter with no reflected wave due to the terminus. The random deviations between the last two curves indicate that the dissipation causing the phase change is not uniform.

POWER TRANSMISSION RATIO

In order to measure the true power transmission ratio, the filter must be replaced by an equivalent section of the line and the terminus must be effectively infinite. This was done by first coupling the filter between the source tube and an ending consisting of a 30-foot coil of tubing, which is effectively infinite by Kirchhoff's formula, and then coupling a straight section of the line. (See Fig. 1.) The single microphone was placed at the end of the filter away from the source and was attached to the ending. The differing reactions on the source for the filter and the straight tube were eliminated by putting sufficient absorbing material in the source tube to damp out the reflected wave.

The theory, which gives P_r as,[2]

$$P_r=\frac{|p_{n+1}|^2}{|p_0|^2}$$

$$=1\Big/\left[\cos^2 nW+\left(\frac{E}{\sin W}+\frac{\sin W}{E}\right)\frac{\sin^2 nW}{4}\right] \quad (8)$$

is plotted with the experimental curves in Figs. 6a and 6b. The check is remarkably good up to 5000 cycles. Above that structural defects and neglected dissipation cause deviations. The increasing depth of the corresponding minima at 3100, 6200, and 9300 cycles may be explained by noting that the cos W curve for these frequencies goes to $+1$, but does not exceed this value. However, if the impedances and lengths of the tubes are not quite the values specified in the theory, the cos W curve will exceed unity at these frequencies and corresponding attenuation bands will appear. The increasing depths of these minima indicate that the errors in structural dimensions are becoming more noticeable at the higher frequencies.

It is a pleasure to express my thanks to Professor A. B. Focke, under whose direction this research was initiated, and to Professor R. B. Lindsay for the suggestions and encouragement given during its progress.

Acoustic Filtration by Membranes*

L. W. LABAW
Brown University, Providence, Rhode Island
(Received January 18, 1942)

This paper presents an experimental and theoretical study of the filtering action of a structure consisting of five stretched circular membranes equally spaced in an acoustic conduit, together with an experimental study of the effect on the transmission of puncturing the membranes with different sized holes. The stretched membrane filter is high pass, while the punctured orifices of sufficient diameter change the structure to a low pass type. This study shows that it is valid to assume plane wave propagation in the circular membrane filter up to 5000 cycles.

THE vibrations of single membranes without discontinuities have been studied theoretically and experimentally, but very little work has been done on punctured membranes. The filtration resulting in an acoustical structure consisting of a series of membranes stretched at equal intervals across an acoustic conduit is examined experimentally here and compared with an approximate theoretical treatment. There is also an experimental study of the effect on the selectivity of making holes of increasing diameter in the membranes of the filter, showing that the punctured holes change the filter from a high pass to a low pass type.

THE FILTER WITH CIRCULAR MEMBRANES

Both experimental and theoretical studies of stretched circular membranes indicate that they respond to certain frequencies and are insensitive to others, depending on the surface density of the membranes and on the linear tension to which they are stretched. A series of such membranes, equally spaced along an acoustic conduit, has a filtering action over a range of frequencies. The usual procedure in dealing with membranes theoretically is to replace the membrane with an equivalent piston with an effective mass one-third that of the membrane and with a stiffness 2π times the linear tension.[1] This approximation checks well with experiments on single membranes below the first resonance frequency. However, when this boundary condition is applied to a series of membranes, though the cut-off frequencies correspond to the experimental ones, the internal structure in the transmission band is not at all in agreement with the experimental results.

A better approximation can be secured by using Rayleigh's expression for the normal displacement of a membrane activated by a pressure constant in space and harmonic in time,[2] as the boundary condition at the membrane. This approximation has the advantage of being applicable beyond the first resonance frequency and gives good agreement with experiment inside the first transmission bands.

For the theoretical treatment we will use the usual filtration theory,[3] which assumes plane wave propagation, and compute the boundary conditions at the membranes from Rayleigh's formula. This should be applicable in the frequency range in which the wave-length is large compared to the diameter of the membranes which introduce non-planar wave forms by their vibrations. Rayleigh's formula is

$$\xi=\frac{2p}{\rho a}e^{i\omega t}\sum_m \frac{J_0(k_{m0}r)}{k_{m0}(\omega^2-q_{m0}^2)J_0'(k_{m0}a)}, \qquad (1)$$

where ξ is the normal displacement of the membrane of radius a at a distance r from the center, activated by a pressure $pe^{i\omega t}$ in which $\omega=2\pi\nu$. The prime refers to differentiation with respect to the argument of the Bessel function. Transverse waves are propagated through the membranes with the velocity $c_1=(\tau/\rho)^{\frac{1}{2}}$, where τ is the linear tension and ρ is the surface density. The q_{m0} are the circular frequencies at

* Presented at the New York meeting of the Acoustical Society of America on October 24, 1941.

[1] G. W. Stewart and R. B. Lindsay, *Acoustics* (New York, 1930), p. 204.

[2] Lord Rayleigh, *Theory of Sound* (London, 1929), Vol. 1, p. 327.

[3] R. B. Lindsay, J. App. Phys. **9**, 612 (1938); **10**, 680 (1939).

which the natural resonances of the membranes occur, and $k_{m0}=q_{m0}/c_1$. The subscript zero refers to the first-order Bessel function of the first kind, while the subscript m refers to a particular symmetrical mode of vibration. The summation is taken over all symmetrical modes, but as is seen from the denominator, the contribution of the various modes is large only when the frequency of excitation approaches one of the resonance frequencies.

If we let $\dot{X}=\int_S \dot{\xi} dS$, where S is the area of the membrane, we have for the first boundary condition of continuity of volume current, at the first membrane,

$$\dot{X}_{12}=\dot{X}_{21}=\dot{X}, \tag{2}$$

where the subscripts 12 and 21 refer to conditions in the air to the left and right of the membrane, respectively, and the dots indicate differentiation with respect to time. The second boundary condition of continuity of pressure gives,

$$p_{21}=\frac{i\dot{X}}{M}+p_{12}, \tag{3}$$

where

$$M=\frac{2\omega}{\rho a}\int_S \sum_m \frac{J_0(k_{m0}r)}{k_{m0}(\omega^2-q_{m0}^2)J_0'(k_{m0}a)}dS. \tag{4}$$

The usual filtration theory with these boundary conditions gives the characteristic transmission function of the equivalent infinite filter as,[3]

$$\cos W=\cos 2kl+(1/2ZM)\sin 2kl, \tag{5}$$

where $Z=\rho_0 c/S$, ρ_0 being the density of air and c the velocity of sound in air, $k=\omega/c$, and $2l$ is the distance between membranes.

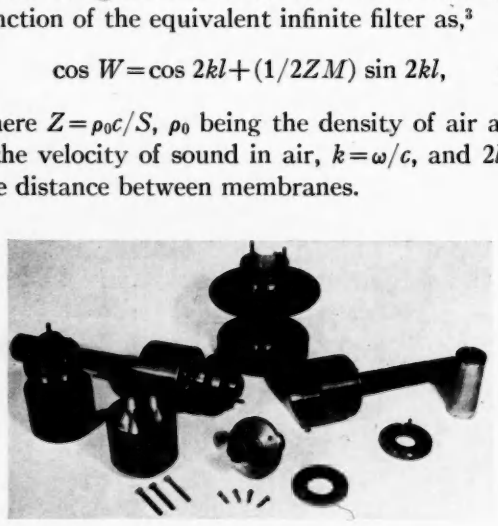


FIG. 1. Photograph of the parts in the filter sections, with two of the membranes used.

The true power transmission ratio for a finite number of sections n, terminate by an effectively infinite line is given as

$$P_r=\frac{1}{\cos^2 nW+\left(\frac{B}{\sin W}+\frac{\sin W}{B}\right)\frac{\sin^2 nW}{4}}, \tag{6}$$

where

$$B=\sin 2kl+1/(ZM)\sin^2 kl. \tag{7}$$

The true power ratio was measured experimentally in a manner similar to that described in the measurement of P_r in the paper "Acoustic Filtration in Parallel Conduit Structures," also appearing in this issue, with the two exceptions that the present conduit was five-eighths inch in diameter and the effectively infinite line was in this case fifty feet long. The arrangement by which the tension was maintained in the membranes is indicated in Fig. 1. The membranes were of thin rubber dental dam which was clamped between two circular rings of equal outside diameters. The lower ring was fitted to the tube within 0.003 inch to prevent sidewise motion while still allowing the ring assembly to slip up and down freely. The upper ring was 0.75 inch inside diameter to prevent it from cutting the rubber, and was 0.005 inch thicker on the inside to assure uniform clamping. The rubber dam was lubricated with graphite and the tube edge over which it was stretched was highly polished. Weights suspended from the ring assembly gave any desired tension. The stand was gently tapped until the membrane came to equilibrium; the ring was then clamped in this position permanently by the three long screws. When the sections are assembled, the result is a continuous acoustic conduit of uniform cross section interrupted by five equally spaced membranes stretched to the same tension. The value of the tension obtained from the suspended weight was checked with the tension found from the frequencies at which the membranes execute their normal modes of vibration.[2] One of the nodal figures is in evidence on the membrane in the background of Fig. 1. These two tension values agreed within one percent. The surface density was computed from the initial and final membrane areas, knowing the surface density of the unstretched membrane.

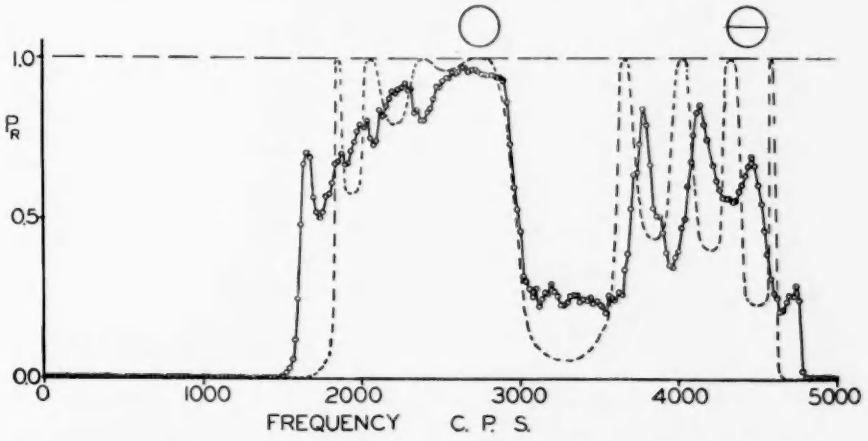


FIG. 2a. Comparison of the experimental and theoretical power transmitted by a five-section filter containing stretched circular membranes, from 0 to 5000 cycles.

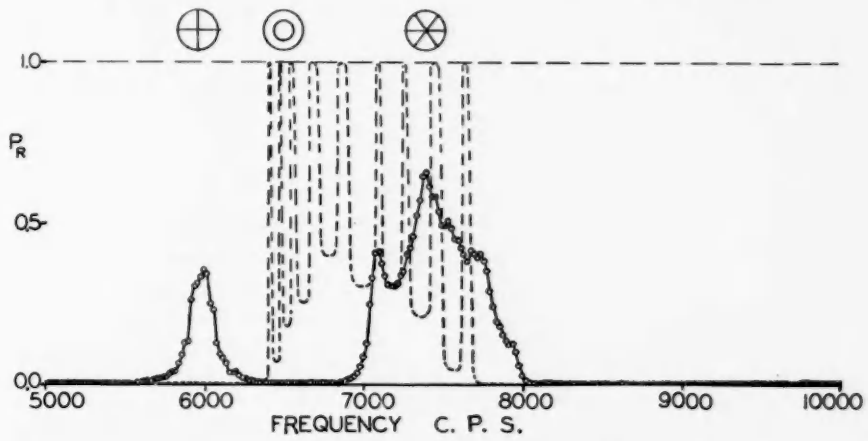


FIG. 2b. Extension of the curves in Fig. 2a from 5000 to 10,000 cycles.

Figures 2a and 2b show the agreement between the theoretical and experimental curves. The values of the tension and surface density used are given in the figure. The circular diagrams at the top of the graph show the nodal lines of the normal vibration modes, above the frequencies at which they occur. Considering the approximation, the agreement is good up to 5000 cycles. The experimental curve indicates that the effect of the membranes on the transmission extends over a wider frequency range than the theory predicts. The disagreement in the interval from 5000 to 10,000 cycles would seem to be owing to the appearance of the unsymmetrical modes. These are ruled out in the theoretical deduction by the assumption of a spatially constant pressure.

ANNULAR MEMBRANE FILTERS

An experimental study has been made of the effect on the selectivity of puncturing the membranes in the filter with holes of increasing diameter. Any theoretical study is made difficult by the existence of a circumferential as well as a radial transverse wave velocity, and a surface of non-uniform density. All three of these are functions of the radius. The boundary conditions at the holes are also uncertain since there is undoubtedly some vortex formation. In the experimental study, the values of the tension and surface density before the holes were punctured were those given in Fig. 2a.

Figures 3a and 3b show the experimental curve for a filter having membranes with orifices 3 mm in diameter plotted with a theoretical

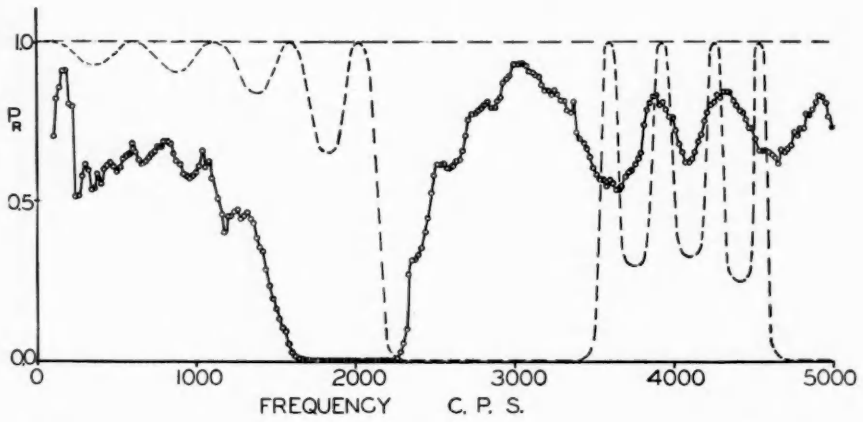


FIG. 3a. Power transmission through a filter containing membranes with holes 3 mm in diameter, with a theoretical curve for infinitely stiff membranes, in the first frequency range studied.

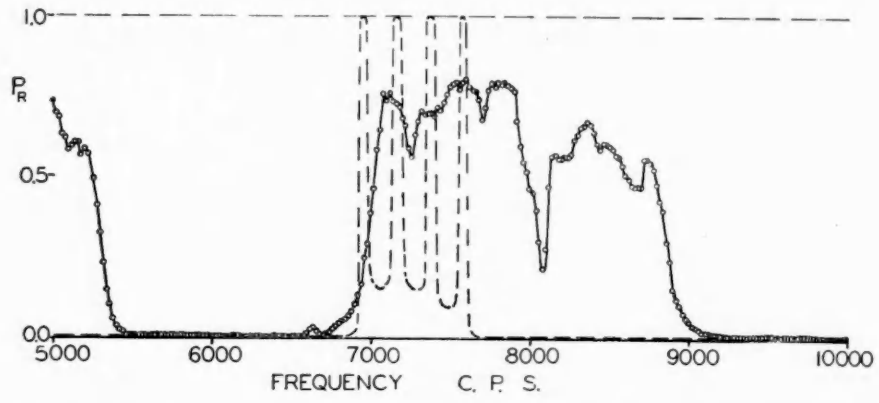


FIG. 3b. Continuation of the curves as given in Fig. 3a, for the second range studied.

curve computed for infinitely stiff membranes with orifices of this size. One of the annular membranes used is shown at the left in Fig. 1. The theoretical curve predicts the change to a low pass filter, although it does not make correct predictions of the attenuation bands or the transmission regions. The value used for the conductivity of the orifice in the computation was that given by Robinson.[4] This experimental curve, together with that in Fig. 2, is an average of three separate runs.

Figures 4a to 4d show the transition from a filter having membranes with no holes to one having annular membranes with hole diameters equal to 3 mm. The filters having $a'=0.0$ mm and $a'=0.25$ mm are high pass and the transmission begins to increase at low frequencies with further increase in the orifice diameter.

Because of the confusion in Fig. 4b, the same curves are replotted on a different scale stepwise in Fig. 5. The ordinate is moved up twenty small scale divisions for each curve representing different sized orifices. This brings out more clearly the transition in the region from 3000 to 5000 cycles.

From the results of this study we may draw the following conclusions: (1) that the assumption of plane waves is applicable in the region below 5000 cycles when dealing with transmission through complete membranes of small diameter (such as the tympanic membrane), and (2) that

[4] N. W. Robinson, Proc. Phys. Soc. London **46**, 772 (1934).

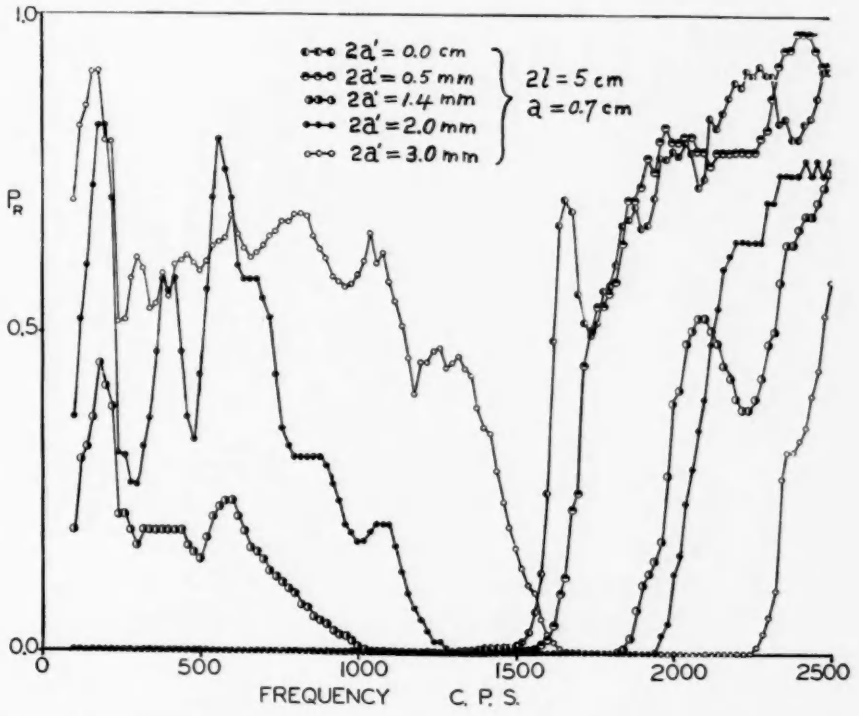


FIG. 4a. A comparison of the power transmitted through filters having membranes with different sized orifices, in the frequency range 0 to 2500 cycles.

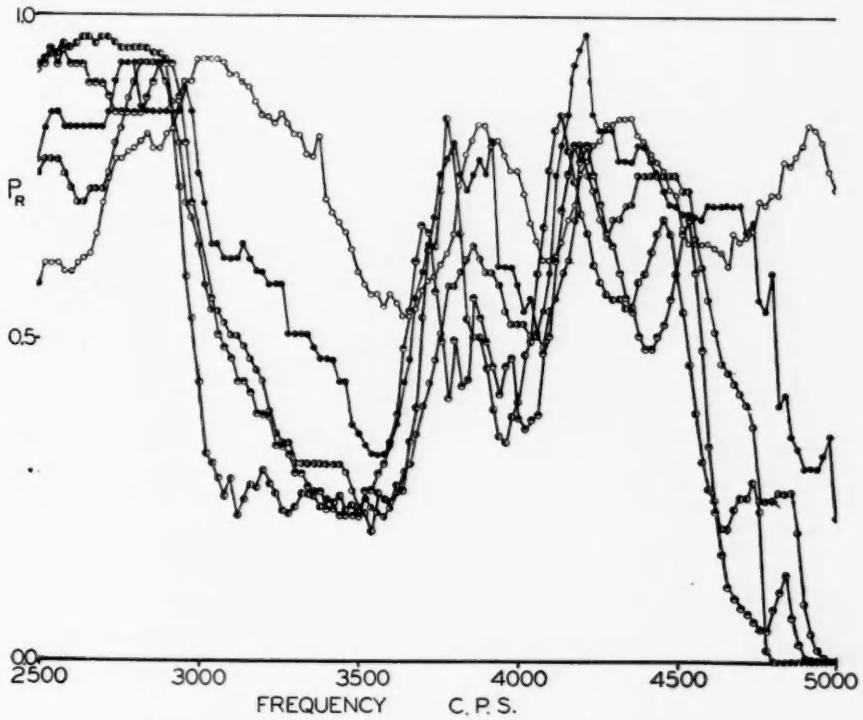


FIG. 4b. Extension of the curves in Fig. 4a in the range 2500 to 5000 cycles.

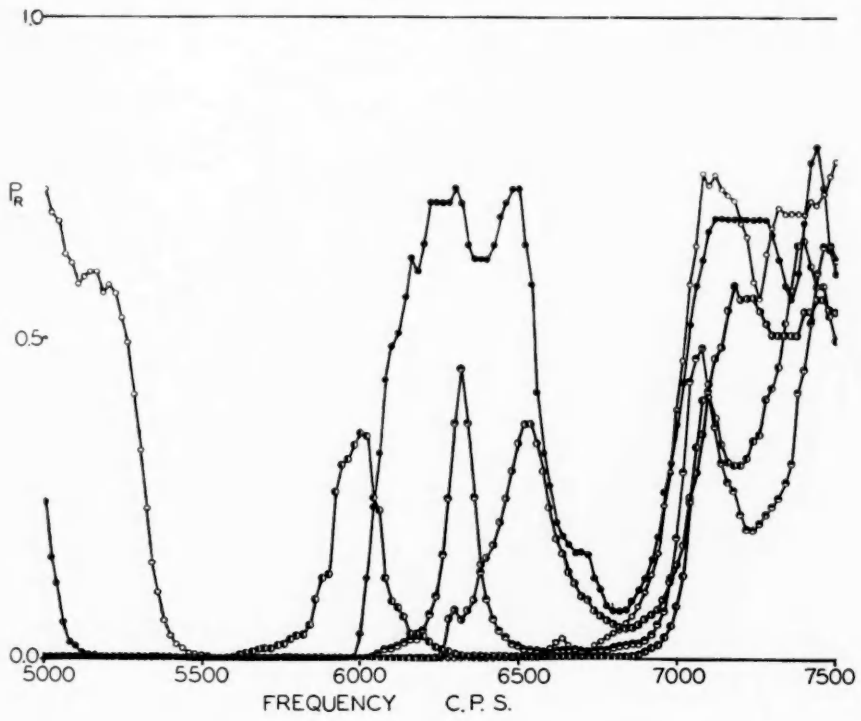


FIG. 4c. Continuation of the curves in Figs. 4a and 4b to the frequency 7500 cycles.

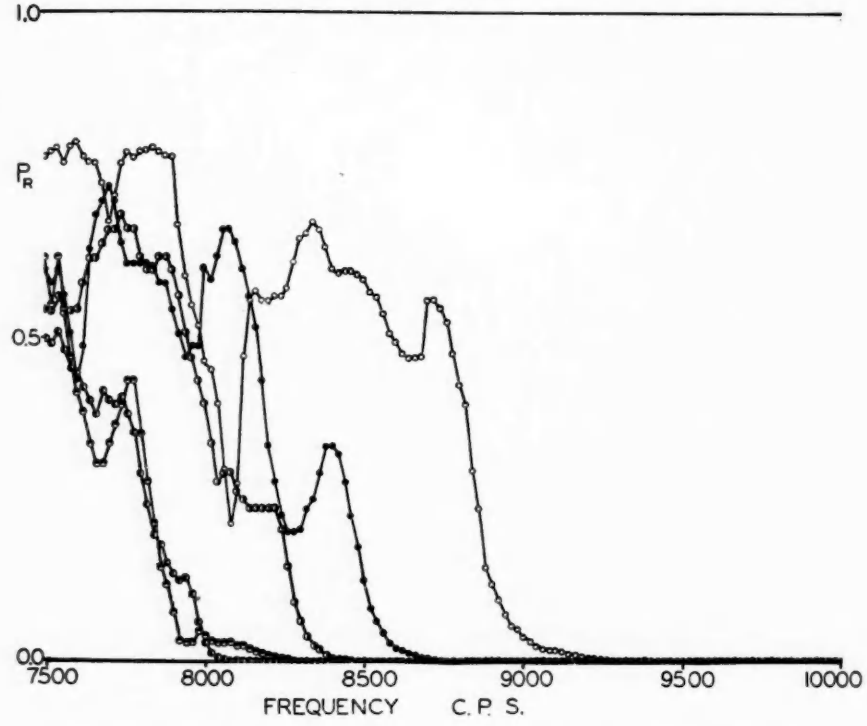


FIG. 4d. Continuation of the curves in Figs. 4a, 4b, and 4c, to 10,000 cycles.

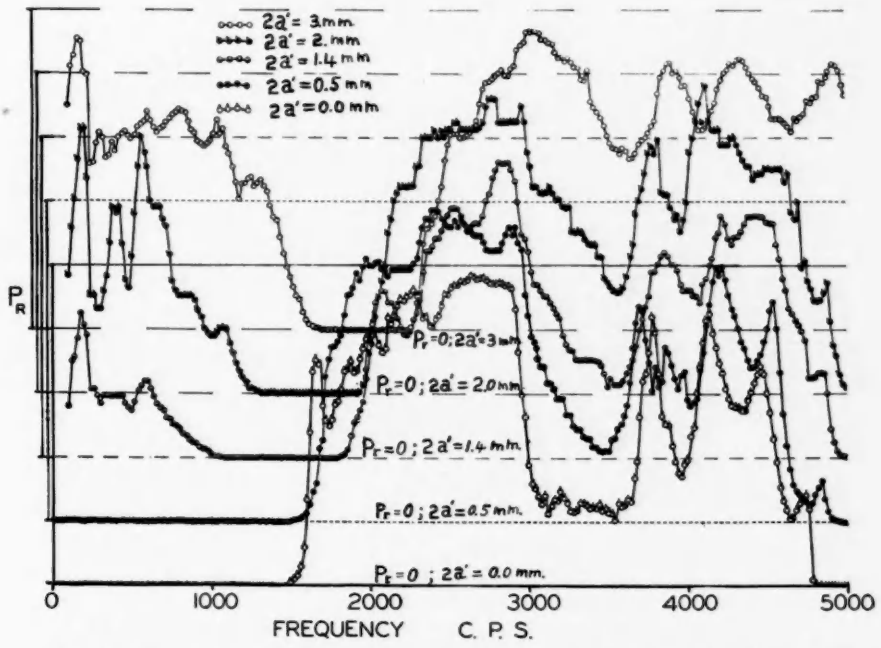


FIG. 5. An experimental study of five filters having membranes with different sized orifices in which the power transmitted is plotted stepwise. The ordinate is shifted twenty small divisions for each increase in orifice diameter.

the selectivity of a pierced membrane (such as a punctured tympanic membrane) is greatly different from the selectivity when the membrane is complete unless the hole is very small.

It is with gratitude that the author acknowledges his indebtedness to Professor R. B. Lindsay for his suggestion of the problem and his interest during its development.

An Analyzer for Sub-Audible Frequencies

H. H. Scott
General Radio Company, Cambridge, Massachusetts
(Received January 5, 1942)

IN many industrial applications, instruments already in use in other fields or developed for other purposes have been adapted to give a certain degree of satisfactory operation. Such adaptations are frequently make-shifts and unsuitable for use by any but highly trained engineers, who will know when to believe and when not to believe the results. The first noise analyzers were adaptations of designs widely and satisfactorily used in the fields of electric power and communications engineering, where the distinguishing characteristics of the service were the unvaryingly recurrent nature of the wave forms under test and the need for the maximum possible degree of selectivity. The degenerative sound analyzer[1] provided an instrument for sound analysis based upon a new principle and designed entirely with the new application in mind. The new circuit was the result of a carefully planned research program intended to produce an analyzer as near as possible to the sound expert's ideal.

For analysis of vibrations extending into the sub-audible frequency range the older types of heterodyne analyzers are generally entirely unsuitable. Having a more-or-less inflexible bandwidth as expressed in cycles per second, which makes them too selective for most types of high frequency noises, they are even less useful at low, sub-audible frequencies because of insufficient selectivity to separate the important components and difficulties with detector balance.

It has been apparent, since the advent of the degenerative type of selective circuit,[2] that it possesses possibilities quite unique for use at low frequencies. The use of the circuit to provide an oscillator having a range extending below 1 cycle per second[3] has already been described. In such applications the fact that no inductances are necessary is a paramount advantage. The size, weight, and cost of the large inductors required at very low frequencies is serious enough, but to these difficulties would be added the distortion generally caused by iron cores and the necessity for magnetic shielding.

The normal method of changing the tuning in a conventional analyzer of the degenerative type results in a constant band width as expressed in percentage of the resonant frequency. This type of circuit therefore has inherently the same type

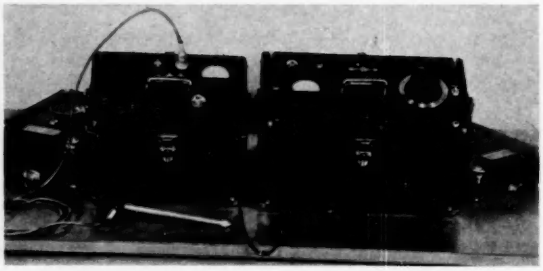
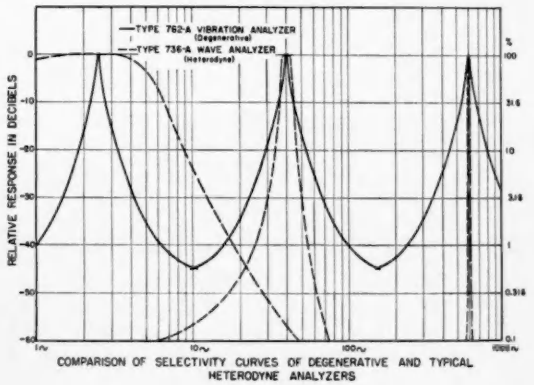


FIG. 1. The Type 762-A Vibration Analyzer (right) matches its companion instrument, the Type 761-A Vibration Meter (left) in appearance. Together these two instruments provide a means for measuring and analyzing practically all types of machinery vibration in the range from 2.5 to 750 cycles per second.



COMPARISON OF SELECTIVITY CURVES OF DEGENERATIVE AND TYPICAL HETERODYNE ANALYZERS

FIG. 2. Selectivity characteristics of the Type 762-A Vibration Analyzer as compared with a typical (Type 736-A) heterodyne type of wave analyzer. Of utmost importance is the vibration analyzer selectivity curve, which maintains a constant shape in terms of percentage of the resonant frequency over the entire range of the instrument.

[1] H. H. Scott, "The degenerative sound analyzer," J. Acous. Soc. Am. **11**, 225–232 (1939).

[2] H. H. Scott, "A new type of selective circuit and some applications," Proc. I. R. E. **26**, 226–235 (1938).

[3] "One cycle per second from the inverse feedback oscillator," *General Radio Experimenter* (1940), Vol. 14, No. 8.

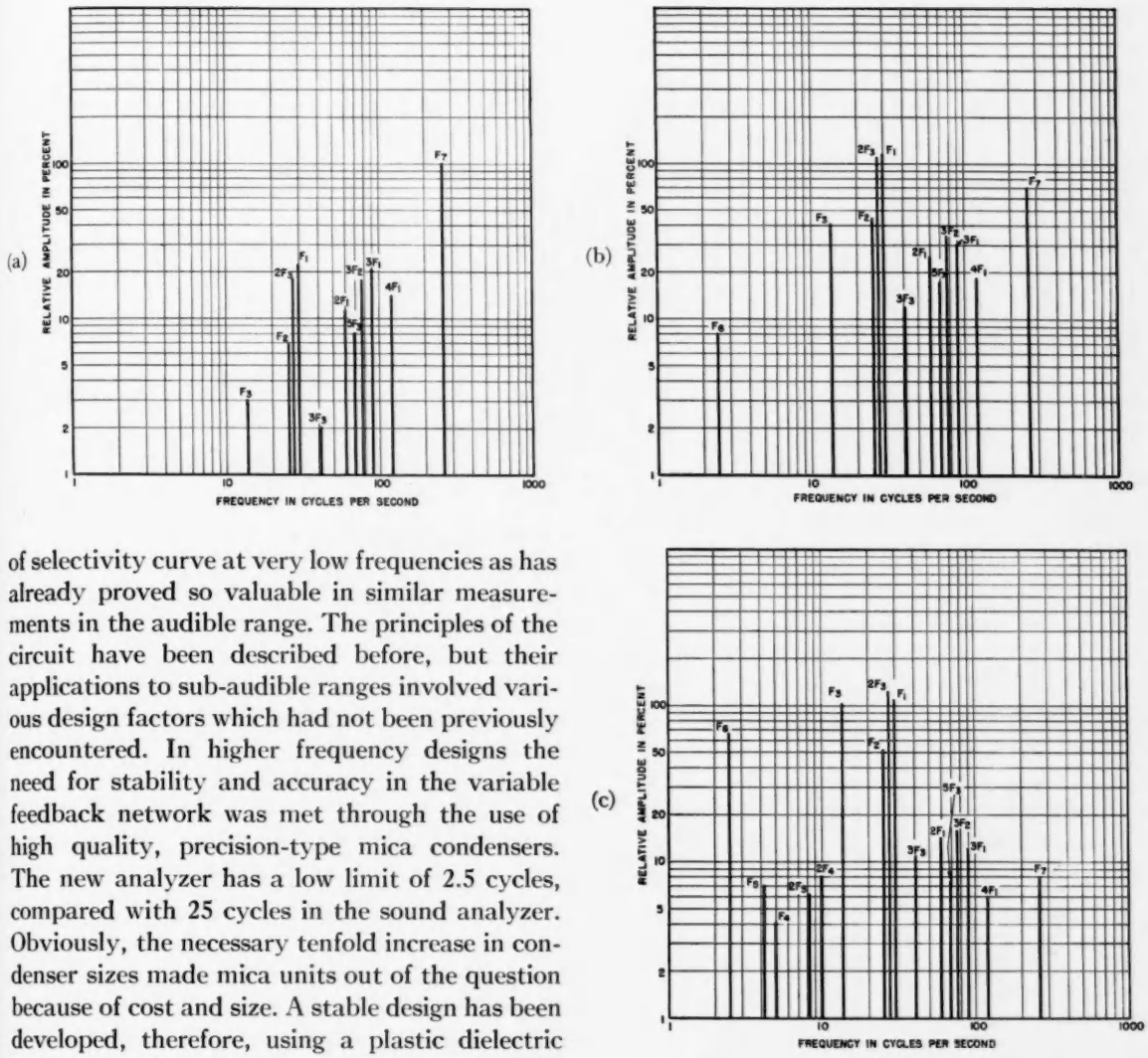


FIG. 3. Typical analyses of a machinery vibration as made with the Type 761-A Vibration Meter and the Type 762-A Vibration Analyzer. (a) Vibration acceleration, (b) Vibration velocity, (c) Vibration displacement.

of selectivity curve at very low frequencies as has already proved so valuable in similar measurements in the audible range. The principles of the circuit have been described before, but their applications to sub-audible ranges involved various design factors which had not been previously encountered. In higher frequency designs the need for stability and accuracy in the variable feedback network was met through the use of high quality, precision-type mica condensers. The new analyzer has a low limit of 2.5 cycles, compared with 25 cycles in the sound analyzer. Obviously, the necessary tenfold increase in condenser sizes made mica units out of the question because of cost and size. A stable design has been developed, therefore, using a plastic dielectric and a suitable moisture-proofing process, which has resulted in a condenser practically as good as mica for this application and with a fraction of the cost and size.

The appearance of the new analyzer is shown in Fig. 1. The general appearance harmonizes with its companion instrument, the Type 761-A vibration meter.[4] Both instruments provide a maximum of portability and serviceability, as a result of compact construction and light-weight, airplane-luggage-type cases. The main controls on the analyzer panel are the large tuning knob and the frequency-range push-button switch, which together provide a substantially logarithmic frequency scale nearly four feet long and covering the range from 2.5 to 750 cycles. The indicating instrument scale reads in the same units as the vibration meter (micro-inches, micro-inches per second, and inches per second per second) but covering a wider range—namely, 120 : 1—with a semilogarithmic characteristic, so that the weaker components in a vibration may be accurately measured. The wide meter range obviates the need of multipliers and allows maximum speed in locating and measuring either weak or strong components.

[4] H. H. Scott, "A general purpose vibration meter," J. Acous. Soc. Am. **13**, 46–50 (1941).

The panel is also equipped with a sensitivity control, push buttons for checking the condition of the batteries and providing quick meter return to speed up the taking of readings, and a switch for providing either an alternating-current or a direct-current output for use with phones or various types of recording devices. The output current is controlled by the same automatic-volume-control circuits which provide a semi-logarithmic scale on the indicating instrument. Hence any linear recording device or indicating device connected to the output will have the same scale deflection curve as the panel indicating instrument.

The actual performance characteristics of the instrument are shown in Fig. 2. These curves correspond with those previously published[1] concerning the sound analyzer. For purposes of comparison similar curves covering the performance of a typical heterodyne-type crystal band-pass analyzer are also shown. These curves indicate that the degenerative circuit provides a degree of selectivity and performance in the low frequency range (below 50 cycles) which is unattainable in conventional heterodyne-type circuits. In addition to this, the vibration analyzer, because of its constant-percentage band width characteristic, maintains an equal ease of tuning and an equal sensitivity shift for frequency-modulated components over its entire frequency range. In this respect it has all the advantages of the degenerative sound analyzer.

Figure 3 shows three typical vibration analyses as made with the analyzer and the vibration meter. The three charts cover the same machine and represent analyses of the acceleration, velocity, and displacement. It is seldom necessary to make all three analyses on one machine, since, in general, one of these three characteristics is of more importance than the others for any particular application. Of course, it is possible to calculate any one of these three analyses from any of the others, but for best accuracy it is desirable to measure the actual one required.

The high degree of complexity of wave form which can be handled by the new analyzer is well shown in these three charts. The variable-frequency motor generator tested had an unusual number of strong vibration components, including the fundamental speeds of the driving motor, the generator, and the various parts of the speed-changer mechanism. Not only are these components shown clearly in the charts, but beats between them are also present. The displacement analysis shows several strong components well below the audible frequency range but capable of causing severe building vibrations. The acceleration analysis, Fig. 3(a), shows clearly that from the standpoint of noise the most important component is F_7, which proved to be due to a bearing defect. This was traced by a simple calculation of the speed at which the balls in the bearing passed over any particular point in the race.

To anyone who has attempted to make accurate analyses of low frequency vibration phenomena these charts will be an evident illustration of the value of the degenerative analyzer for use at such frequency ranges. The combination of vibration meter and analyzer provides engineers with simple, inexpensive, convenient, and, of most importance, accurate means for determining the components of low frequency vibrations. Vibration is often the cause not only of noise and annoyance, but also of serious disasters resulting from mechanical failures. It is hoped that these developments will be of real service to our industry and our country.

Relation of Audiogram Measurements to Hearing Aid Characteristics Based on Commercial Experience

FRED W. KRANZ AND CARL E. RUDIGER
Sonotone Corporation, Elmsford, New York
(Received December 15, 1941)

IT is probable that the original development of the audiometer may be credited to the desire for a tool for research on the problems of hearing. However, the present widespread use of the audiometer is for the measurement of deficiencies in hearing by otologists and also by organizations interested in the value of audiograms as a help in the fitting of hearing aids.

The Sonotone Corporation is one of these latter organizations. It has a considerable number of offices throughout the country, and audiograms are taken of all of the people with whom the dealers come in contact as prospective users of hearing aids. A copy of each of these audiograms is sent to the home office, and thus a large collection of audiograms has been built up. The following discussion is based on this group of audiograms and the experience obtained from the use of these audiograms in the fitting of hearing aids.

Specifications for the performance of audiometers have been set up by The American Standards Association. These standards cover the matters of the frequencies which should be obtainable from the audiometer, the purity of the tones, the accuracy of the calibration, the available intensity ranges, etc. However, the intensity level for minimum audibility has not as yet been set in these standards, and this is, of course, the basic consideration for the data presented in an audiogram. The principal possibility of a difference of opinion as to the proper intensity to represent minimum audibility lies in the experience of the observers whose results are used for the determination of the minimum standard audibility curve. Either practiced or non-practiced observers may be used for the determination of this zero-level curve. A practiced observer will have a curve approximately ten decibels lower in intensity than will the non-practiced observer. There are indications that the minimum audibility curve based on the determinations of the United States Public Health Service Survey of 1936 will eventually be accepted as standard and such values as are mentioned in the present paper are based on this level.

The interest of a commercial company in the measurement of hearing and the plotting of the results on an audiogram, implies that hearing aids are available which are adaptable to various conditions as revealed by the audiogram and, of course, this is true. These factors of adaptability are the use of a bone-conduction or an air-conduction receiver, the choice of which ear is to be fitted, and the characteristics of the instrument itself. The performance of the instrument is dependent upon the nature of the frequency response of the three principal components of the instrument—the transmitter, the amplifier, and the receiver, as well as upon the voltage of the battery which is used as it affects the general level of the sound output of the instrument.

The frequency response of the transmitter in the case of vacuum tube instruments which use a crystal type of transmitter may be controlled to some extent by changes in the transmitter housing particularly to reduce the low frequency response in cases where this is desired. The response characteristics of the vacuum tube amplifier may be controlled by a proper choice of the components of the electrical circuits, while the response of the receiver may be influenced by the location of the resonant frequencies of the vibrating system.

The transmitter-amplifier combination in one of our models has a frequency characteristic which is flat within 5 db except for a small accentuation which is introduced in the 2000–2500 cycle frequency band. A variable tone control adjustment is available in this instrument which allows a suppression of low frequencies along a line essentially pivoted about 2500 cycles, and amounting to as much as 25 db at 400 cycles. Another model has a tone control which allows either suppression of the low frequencies, suppression of the high frequencies or suppression of both low and high

frequencies, as well as giving the full available frequency response. The suppressions in this case are of the order of 15 db.

Air-conduction receivers are available with maximum responses at 1000, 1200, 1400, 2000, and 2500 cycles. Bone-conduction receivers are furnished with maximum responses at 1200, 1400, and 1600 cycles. All of these receivers have relatively suppressed peaks of resonance so that their response is reasonably flat.

With these available variables in the instruments, the audiograms are studied not only to select the best combination for the use of the individual, but with particular interest in those cases in which it has proved difficult to provide satisfactory hearing. These difficult cases furnish the basis for further developments of hearing aids.

The audiograms may for simplicity be grouped into three classifications as regards the air-conduction curves, which may be described as a flat characteristic, a rising characteristic or a falling characteristic in going from 500 to 2000 cycles. A flat characteristic is taken as one in which the variation is not over 5 db between these two frequencies.

We find that about 44 percent of the audiograms show a flat characteristic, about 43 percent show a falling characteristic, and only 13 percent show a rising characteristic. These percentages indicate the relatively greater prevalence of high frequency loss as compared with low frequency loss, even below 2000 cycles. Of those with a predominating low frequency loss by air conduction, two-thirds have excellent bone conduction.

On the basis of measurements of air conduction for the better ear, we find that about 10 percent of our audiograms show a loss of less than 40 db, 45 percent show a loss between 40 and 60 db, 25 percent show a loss between 60 and 80 db, while 10 percent show a loss greater than 80 db.

Some general comments on hearing loss as related to hearing aids may be made, before considering these relations in detail. As a rule, few people whose air-conduction loss is less than 25 decibels suspect that they have any hearing difficulty, and therefore there is a much smaller percentage of these cases represented in our collection of audiograms than would be found in a general survey of the population. A hearing aid is of no appreciable benefit to a person with less than 25-decibel loss, although these smaller losses are undoubtedly of significance as a matter of public health and in connection with the possibility of measures to avoid a progressive deterioration of hearing. The same comment is applicable to people who have a loss of even considerably more than 25 decibels in the region of 4000 cycles or above.

In considering the cases in which there is a very large deficiency in hearing, we were inclined to believe that if a person had a loss of about 90 decibels, he would not receive any appreciable help from a hearing aid. However, we have been rather confounded by the quite satisfactory results obtained by some users whose audiograms showed these great deficiencies. There seem to be a number of cases in which a little help is of much more significance than could be anticipated from the audiogram. The high intensity level at which such an audiogram is made would seem to indicate that the results when using a hearing aid are not due to recruitment as usually understood.

If a person has a deficiency of 70 decibels or more in one ear while the other ear has a deficiency of less than 25 db, he will receive no benefit from the use of a hearing aid.

The value of a hearing aid and the selection of a hearing aid best suited to the individual can, in most cases, be made on the basis of the audiogram curves between 1000 and 2000 cycles. This region is the most important from the standpoint of speech articulation and it is, of course, on the basis of hearing and understanding of speech that the value of a hearing aid is judged. Also, in the region below 1000 cycles the variations in hearing with respect to that at 1000 cycles are not as great in the majority of cases as the variations above this frequency.

We have found that in a large number of cases, if not the majority of cases, the user of a hearing aid will find its performance more satisfactory and comfortable if the amplification of the low frequencies is less than sufficient to provide him with an over-all flat frequency audibility. Perhaps this is not really a characteristic only of people who are hard of hearing as it may be that all of us would prefer to be partially protected against low frequency sounds as compared with

the higher frequency sounds involved in speech. A somewhat parallel situation may be suggested in connection with music, as tone controls on radios allow a user to vary the balance between the high and low frequency ranges of reproduction and there are indications that the balance between these high and low frequency ranges as produced by available instruments or orchestras is not necessarily the balance to which many people prefer to listen.

In considering the fitting of a hearing aid on the basis of an audiogram, a choice is first made as between bone- and air-conduction receivers.

There are two types of audiograms in which a bone-conduction fitting is indicated, one being the case in which the air-conduction loss is more than twice the bone-conduction loss (as expressed in decibels), and the other being the case in which the air-conduction loss is more than 40 db greater than the bone-conduction loss. If the subject can hear equally well with air and bone conduction, the latter is indicated if air conduction is ruled out because of physical factors such as itching or discharging ears or peeling of the skin of the canal linings of the ear. A further guide post is the amount of residual hearing which the subject has and can make use of if the ear is left open. This consideration will also affect the choice of which ear is to be fitted. In borderline cases, the final choice between bone and air receivers is made on the basis of tests of articulation and distance hearing. In our experience, we find that about 40 percent of the subjects are best fitted with bone-conduction receivers, while 60 percent are most satisfactorily fitted with air receivers.

Our experience has shown that the subject is usually best fitted when his audiogram curve combined with the corrective curve of the response of the instrument results in a curve which rises slightly with increase of frequency. This adaptation is obtained by a proper choice of the setting of the tone control on the instrument together with the selection of a receiver with a suitable resonance characteristic.

In all cases a final check of the effectiveness of the hearing aid is made on the basis of articulation tests and the distance range of satisfactory hearing, using the fitting indicated by the audiogram as well as other closely related choices.

We have found that on the basis of the principles mentioned, we are able to select by inspection of audiograms the most satisfactory hearing aid combination for over eighty percent of the people to be fitted.

There are a number of cases in which the hearing impairment has been of long duration so that the subject has built up an interpretation of speech based on a distorted frequency reception. In some of these cases, the fitting of the hearing aid has to be adapted to give somewhat the quality of sound to which the subject has been accustomed and it will be only after a period of re-education of normal sound vocabulary that the subject reaches the place where the fitting indicated by his audiogram will prove to be most satisfactory for him.

One type of audiogram may be mentioned which may be indicative of difficulty in obtaining a satisfactory and comfortable fitting. This is the case in which the loss by air conduction is essentially uniform with frequency, giving a flat audiogram curve at a 50- to 60-db level, with the bone-conduction audiogram curve close to the air-conduction curve. In these cases it is found advisable to plot a curve of the level of uncomfortable loudness. If the difference between the curves of minimum audibility and uncomfortable loudness is small, it is often found impossible to give sufficient amplification to extend the hearing distance by an appreciable amount, at least at the initial fitting, because of discomfort to the subject. At this stage, the higher frequencies may be particularly objectionable to the subject although necessary to proper intelligibility. Many of these cases gradually acquire a tolerance for the amplified sound, so that eventually the corrective amplification can be built up to a useful and satisfactory level.

There are some cases in which the mental faculty of interpretation of speech has become defective and although the audiogram may show only a moderate loss, difficulties in fitting of a hearing aid will be experienced. These cases are referred to an otologist for medical attention.

In cases of partial deafness from birth of such extent as to interfere with the proper development of a speech vocabulary, the enhancement of

frequencies, as well as giving the full available frequency response. The suppressions in this case are of the order of 15 db.

Air-conduction receivers are available with maximum responses at 1000, 1200, 1400, 2000, and 2500 cycles. Bone-conduction receivers are furnished with maximum responses at 1200, 1400, and 1600 cycles. All of these receivers have relatively suppressed peaks of resonance so that their response is reasonably flat.

With these available variables in the instruments, the audiograms are studied not only to select the best combination for the use of the individual, but with particular interest in those cases in which it has proved difficult to provide satisfactory hearing. These difficult cases furnish the basis for further developments of hearing aids.

The audiograms may for simplicity be grouped into three classifications as regards the air-conduction curves, which may be described as a flat characteristic, a rising characteristic or a falling characteristic in going from 500 to 2000 cycles. A flat characteristic is taken as one in which the variation is not over 5 db between these two frequencies.

We find that about 44 percent of the audiograms show a flat characteristic, about 43 percent show a falling characteristic, and only 13 percent show a rising characteristic. These percentages indicate the relatively greater prevalence of high frequency loss as compared with low frequency loss, even below 2000 cycles. Of those with a predominating low frequency loss by air conduction, two-thirds have excellent bone conduction.

On the basis of measurements of air conduction for the better ear, we find that about 10 percent of our audiograms show a loss of less than 40 db, 45 percent show a loss between 40 and 60 db, 25 percent show a loss between 60 and 80 db, while 10 percent show a loss greater than 80 db.

Some general comments on hearing loss as related to hearing aids may be made, before considering these relations in detail. As a rule, few people whose air-conduction loss is less than 25 decibels suspect that they have any hearing difficulty, and therefore there is a much smaller percentage of these cases represented in our collection of audiograms than would be found in a general survey of the population. A hearing aid is of no appreciable benefit to a person with less than 25-decibel loss, although these smaller losses are undoubtedly of significance as a matter of public health and in connection with the possibility of measures to avoid a progressive deterioration of hearing. The same comment is applicable to people who have a loss of even considerably more than 25 decibels in the region of 4000 cycles or above.

In considering the cases in which there is a very large deficiency in hearing, we were inclined to believe that if a person had a loss of about 90 decibels, he would not receive any appreciable help from a hearing aid. However, we have been rather confounded by the quite satisfactory results obtained by some users whose audiograms showed these great deficiencies. There seem to be a number of cases in which a little help is of much more significance than could be anticipated from the audiogram. The high intensity level at which such an audiogram is made would seem to indicate that the results when using a hearing aid are not due to recruitment as usually understood.

If a person has a deficiency of 70 decibels or more in one ear while the other ear has a deficiency of less than 25 db, he will receive no benefit from the use of a hearing aid.

The value of a hearing aid and the selection of a hearing aid best suited to the individual can, in most cases, be made on the basis of the audiogram curves between 1000 and 2000 cycles. This region is the most important from the standpoint of speech articulation and it is, of course, on the basis of hearing and understanding of speech that the value of a hearing aid is judged. Also, in the region below 1000 cycles the variations in hearing with respect to that at 1000 cycles are not as great in the majority of cases as the variations above this frequency.

We have found that in a large number of cases, if not the majority of cases, the user of a hearing aid will find its performance more satisfactory and comfortable if the amplification of the low frequencies is less than sufficient to provide him with an over-all flat frequency audibility. Perhaps this is not really a characteristic only of people who are hard of hearing as it may be that all of us would prefer to be partially protected against low frequency sounds as compared with

the higher frequency sounds involved in speech. A somewhat parallel situation may be suggested in connection with music, as tone controls on radios allow a user to vary the balance between the high and low frequency ranges of reproduction and there are indications that the balance between these high and low frequency ranges as produced by available instruments or orchestras is not necessarily the balance to which many people prefer to listen.

In considering the fitting of a hearing aid on the basis of an audiogram, a choice is first made as between bone- and air-conduction receivers.

There are two types of audiograms in which a bone-conduction fitting is indicated, one being the case in which the air-conduction loss is more than twice the bone-conduction loss (as expressed in decibels), and the other being the case in which the air-conduction loss is more than 40 db greater than the bone-conduction loss. If the subject can hear equally well with air and bone conduction, the latter is indicated if air conduction is ruled out because of physical factors such as itching or discharging ears or peeling of the skin of the canal linings of the ear. A further guide post is the amount of residual hearing which the subject has and can make use of if the ear is left open. This consideration will also affect the choice of which ear is to be fitted. In borderline cases, the final choice between bone and air receivers is made on the basis of tests of articulation and distance hearing. In our experience, we find that about 40 percent of the subjects are best fitted with bone-conduction receivers, while 60 percent are most satisfactorily fitted with air receivers.

Our experience has shown that the subject is usually best fitted when his audiogram curve combined with the corrective curve of the response of the instrument results in a curve which rises slightly with increase of frequency. This adaptation is obtained by a proper choice of the setting of the tone control on the instrument together with the selection of a receiver with a suitable resonance characteristic.

In all cases a final check of the effectiveness of the hearing aid is made on the basis of articulation tests and the distance range of satisfactory hearing, using the fitting indicated by the audiogram as well as other closely related choices.

We have found that on the basis of the principles mentioned, we are able to select by inspection of audiograms the most satisfactory hearing aid combination for over eighty percent of the people to be fitted.

There are a number of cases in which the hearing impairment has been of long duration so that the subject has built up an interpretation of speech based on a distorted frequency reception. In some of these cases, the fitting of the hearing aid has to be adapted to give somewhat the quality of sound to which the subject has been accustomed and it will be only after a period of re-education of normal sound vocabulary that the subject reaches the place where the fitting indicated by his audiogram will prove to be most satisfactory for him.

One type of audiogram may be mentioned which may be indicative of difficulty in obtaining a satisfactory and comfortable fitting. This is the case in which the loss by air conduction is essentially uniform with frequency, giving a flat audiogram curve at a 50- to 60-db level, with the bone-conduction audiogram curve close to the air-conduction curve. In these cases it is found advisable to plot a curve of the level of uncomfortable loudness. If the difference between the curves of minimum audibility and uncomfortable loudness is small, it is often found impossible to give sufficient amplification to extend the hearing distance by an appreciable amount, at least at the initial fitting, because of discomfort to the subject. At this stage, the higher frequencies may be particularly objectionable to the subject although necessary to proper intelligibility. Many of these cases gradually acquire a tolerance for the amplified sound, so that eventually the corrective amplification can be built up to a useful and satisfactory level.

There are some cases in which the mental faculty of interpretation of speech has become defective and although the audiogram may show only a moderate loss, difficulties in fitting of a hearing aid will be experienced. These cases are referred to an otologist for medical attention.

In cases of partial deafness from birth of such extent as to interfere with the proper development of a speech vocabulary, the enhancement of

sound by a hearing aid may be of help, but special training is invariably also necessary.

It should be here noted that a number of people have made contributions to these adaptations of hearing aids to compensate for various types of deficiencies and to the development of suitable hearing aids to meet the demonstrated needs.

In summary, it may be said that while complete accuracy has not yet been attained in the process of selection of hearing aids on the basis of audiometric measurements, yet this method together with improvements in instruments now enables hearing aids to be fitted to give much more satisfaction and comfort to the user than was formerly possible.

Dynamic Auditory Localization

1. The Binaural Intensity Disparity Limen*

ADELBERT FORD
Lehigh University, Bethlehem, Pennsylvania
(Received November 13, 1941)

THE relative importance of intensity-disparity and phase-disparity in binaural sound localization appears to require data which have never been taken. Psychologists who are skeptical of the importance of phase ratio rest heavily on the postulations of Wilson and Myers[1] for the assumption that all phase ratios, even with rigidly controlled intensity equality at the *external* ears, are accompanied by standing-wave amplitude differences at the *inner ears* as a result of cross-cranial acoustical leakage (largely bone-conduction). The physical basis of this leakage has never been denied by anyone. The followers of phase-ratio theory are inclined to think that the amount of cross-cranial leakage is too small to have a discriminable effect. Obviously, we should settle the dispute by measurement and not opinion.

It appears that, in order to evaluate the seriousness of the Wilson and Myers error, we must have the following determinations:

(1) The amount of sound energy crossing the skull.

(2) The speed of transmission, in order to know at what phase position the leakage wave is added to the stimulus wave.

(3) How small a binaural intensity difference can be discriminated at all (binaural intensity-disparity limen).

The first was alleged by Lane[2] on the basis of secondary maxima in binaural beats, and estimated by Stewart[3] in theoretical equations, but we prefer to assume it has never been measured directly. The second determination has certainly never been reliably measured. The third is the subject of this paper, but may have been previously measured by Upton,[4] if we assume that this last worker controlled certain unmentioned possibilities of error (he furnished no proof that "time difference" or phase ratio were rigidly excluded).

Psychologically, localization responses may be *learned* with perceptual stimulus patterns. An artificial experimental situation may depart so far from the natural stimuli required that no responses at all result. In everyday life, without laboratory restrictions, binaural stimuli are nearly always *dynamic*, i.e., changing in some definite and *familiar* order. People either rotate their heads in listening to a stationary sound, or hold still while listening to a moving sound source. It is only necessary to watch a person listening to a strange sound in order to verify this.

Now Stewart used binaural beats, with the phase ratio *dynamically* changing on a sine function, for demonstrating localization by phase disparity. Although this dynamic pattern was probably close to that of the everyday life situation, only 11 out of 23 subjects exhibited localization responses, and he explains the lack of complete success on the basis of individual differences. But when he experimented on intensity disparity he used static disparities rather than moving ones. As a result of this situation he reports occasional "lapse effects" in which there was no localization response for intensity differences as great as 200 : 1, and these occurred at various frequencies lower than 1024 cycles. It is our belief that had he used dynamic stimulus patterns for *both* phase and intensity, he would have secured a different result for intensity cues. (It is to be noted that the *amount* of phase disparity in a binaural beat situation, for tones at

* We wish to thank Princeton University for the courtesy-fellowship and the research facilities which made these data possible. Particularly, we wish to express our appreciation to Professors C. W. Bray and C. H. Wedell for acting as subjects, and to Professor E. G. Wever for certain experimental suggestions. The author is indebted to the various graduate students for acting as subjects.

[1] H. A. Wilson and C. S. Myers, "The influence of binaural phase difference on the localization of sounds," Brit. J. Psychol. **2**, 363–385 (1906–1908).

[2] C. E. Lane, "Binaural beats," Phys. Rev. **26**, 401 (1925). Bell Lab. Reprints B-155-1.

[3] G. W. Stewart, "The theory of binaural beats," Phys. Rev. **9**, 514–528 (1917).

[4] M. Upton, "Differential sensitivity in sound localization," Proc. Nat. Acad. Sci. **22**, 409–412 (1936).

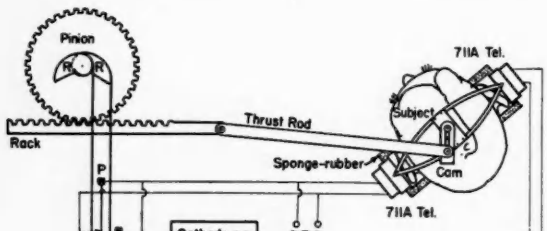


FIG. 1. A schematic diagram of apparatus for producing pure dynamic intensity disparity on a function similar to that of Firestone's curves. Dimensions are not scale proportions.

Stewart's experimental frequencies, is vastly greater than that found under natural conditions.) The fact that not all people show localization to phase disparity was later verified by Wightman and Firestone on the basis of static stimuli.

Our contention is that pure intensity disparity should be investigated with a dynamic stimulus pattern which is a close approximation to *one* of those used in everyday life. Obviously there are as many intensity progressions, under natural conditions, as there are distances of the sound source and audible frequencies. It will be a small contribution if we show the errors of localization, in pure intensity disparity, when just *one* natural pattern is used. This will favor the operation of natural localization habits.

Assuming that Firestone's curves[5] for intensity disparity are a close approach to the physical stimuli under natural conditions, we devised apparatus which would reproduce an intensity function as the subject rotated his own head, or swung his body around while sitting on a swivel chair. Two assumptions seemed necessary in the apparatus design to achieve this result: (1) that the intensity at each ear varies inversely as the square of the distance from a sound source, and (2) that the distance of each ear from the sound source varies as a sine-cosine function, *if the cranial axis is a fixed position*. Therefore, we varied the intensity by the use of a slide-wire potentiometer which combined the logarithmic progression with the sine-cosine functions. No mechanical provision was made for "sound shadow" effects, since we matched the progression secured from Firestone's 256-cycle stimulus, and this showed a relatively small amount of reflection and absorption. Phase disparity, "time difference" of the wave front, and overtone disparity were rigidly excluded, as will be evident from the nature of the apparatus and the mode of procedure.

Figure 1 shows the essential features of the apparatus (not drawn to scale). The tones were generated in a Western Electric 6010B pure tone oscillator. The output was conducted through a matched attenuator, which was so adjusted that the headphones on the subject gave a stimulus exactly 50 decibels above threshold when the binaural intensity was at equality. The output of the attenuator was passed through a General Radio stepdown transformer T with straight-line function for audible frequencies, in order to produce a voltage adapted to the headphones. This low voltage output was then passed through a potentiometer resistance slide wire P–P stretched straight in order to prevent changes in impedance. Movable wire leads were kept as far apart as possible for the same reason. The movable sliding contacts S and S were of the multiple-finger bronze type, and tapped experimental voltages for each of the headphones to produce the intensity differences.

The slide-wire contactors were tested on direct current, with both human hearing and a cathode-ray oscillograph to be certain that no audible noise was produced while voltages were being changed. The cathode-ray oscillograph was continuously in the circuit during the taking of all readings. The sliding contactors S and S were moved by thin wires rolling over the brass drums R and R which had been cut with radii on a logarithmic progression in order to change the intensity on the order of the inverse-square law. These drums were in turn rotated by a rack-and-pinion and thrust rod from a cam and shaft attached to the subject's head, the cam producing an approximation of the sine-cosine function of the relation of the ears with respect to the sound

[5] F. A. Firestone, "The phase difference and amplitude ratio at the ears due to a source of pure tone," J. Acous. Soc. Am. 2, 260–270 (1930).

source as found in natural conditions of head-turning movements.

The voltages supplied to the receivers were now measured and the values plotted on top of Firestone's curves. Fig. 2 shows how close we came to the values of Firestone's curve for a frequency of 256 cycles, source at 20 cm. The heavy, solid line is a tracing of Firestone's curve. The broken line gives the values from our potentiometer *while the head was being turned*. It is necessary to state here that in using the 2000-cycle frequency we did not attempt to duplicate the shape of the sound-shadow phenomenon. Much more complex apparatus would have been required. The shape of the 256-cycle progression was used throughout.

The headphones were Western Electric No. 711A "distortionless" monitoring phones—the best available at the time of the experiment—mounted over the ears with $1\frac{1}{2}$ inches of sponge rubber for insulation around the acoustic opening, and with no pressure of the shells directly against either the pinnae or the skull bones. Since the phase of the phones were kept at equality there could be no question of variable interference through the supporting saddle. The tone was turned on *slowly*, at the attenuator, just before the readings began, to avoid any possible time disparity at the phones.

The criteria for phase equality are important for those who might try to explain our results by uncontrolled phase disparity. At no time was there any visible change in phase relation of the two receivers as indicated by Lissajous figures in the cathode-ray screen, and this check was used constantly. However, at the position of intensity equality it was possible to use the nulling method described by Firestone. This proved to be far finer as a means of exhibiting phase inequality than any other method available, showing phase disparities smaller than 1°. Although the manufacturer had supposedly delivered matched phones, there was a slight difference in the impedance characteristics of the phones and this was exactly corrected by adding a capacity of .015 μf to the right phone in order to achieve perfect nulling.

It was possible to set the position of perfect intensity equality at any place in a 360° circle around *S*'s head, and this point was indicated on a dial, invisible to *S*. Then he was instructed to rotate his head and try to discover where the position of binaural intensity equality was and "point your nose at the sound." By this dynamic method of duplicating the natural conditions of the order of intensity change for each ear it was possible to eliminate the front-back ambiguity of cues so often reported in the experiments with static stimuli. There was just one position of the head where *S* should theoretically "point his nose at the sound," and for all but the small ratios the tables show that there was no appearance of the front-back confusion. This being true, then an average error of ±90° should represent "pure chance," counting degrees right or left to 180 on the opposite side of the field from the "front" position. The slide-wire mechanism was shielded from visibility and the experimenter himself did not know where the equality position was while *S* made his judgment by rotating his head back and forth and finally "pointing his nose at the sound." *S* made judgments with eyes closed to guard against any further chances of suggestive errors.

Two experimental frequencies were now selected, 200 and 2000 cycles. The choice was determined solely by a curiosity to see if a frequency well above the supposed limit for the operation of phase effect (where intensity effect is supposed to be the major factor) produced a different result from a frequency well below the upper limit for phase effect. The score of each subject was the angular error of his head from the position of absolute intensity equality after he had stopped rotating his head and decided that his "nose was pointing at the sound." The

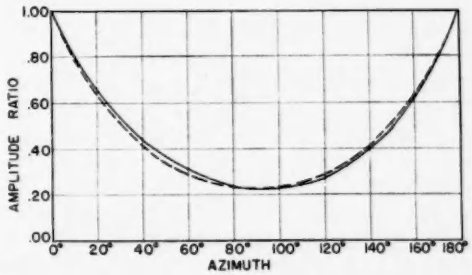


FIG. 2. Amplitude disparity plotted over Firestone's empirical curve for a tone of 256 cycles. The heavy line is a tracing of Firestone's curve. The broken line represents the disparity delivered by the experimental apparatus.

TABLE I. Localization errors for a frequency of 200 cycles, expressed in degrees of divergence from median plane fixation.

Subject	Disparity in decibels	Errors in degrees: Number of reading 1	2	3	4	5	6	7	8	9	10	Arith. av.
A. F.	13.2	−2	22	43	−14	−15	−29	5	−40	−6	5	18.1
A. F.	6.0	−20	−30	−18	−14	−28	−61	−16	−14	18	8	22.7
A. F.	1.9	−75	67	−42	20	−19	−49	30	−51	−65	−4	42.2
A. F.	0.9	32	2	120	−164	−57	48	−58	106	120	−20	62.7
C. H. W.	13.2	6	−12	−10	15	1	10	1	2	15	9	8.1
C. H. W.	6.0	4	48	27	2	−31	−22	16	−63	−63	−13	28.9
C. H. W.	1.9	48	84	78	−14	−41	37	28	15	100	−8	45.3
C. H. W.	0.9	63	−26	47	23	−68	−22	28	−23	2	−1	30.3
C. H. W.	.4	−27	−34	−150	−87	33	146	126	53	−16	−160	83.2
G. O.	13.2	12	9	14	8	9	27	6	19	9	−1	11.4
G. O.	6.0	3	3	14	24	66	−9	23	46	30	12	23.0
G. O.	1.9	18	−21	43	71	−42	9	72	37	95	69	47.7
G. O.	0.9	−140	150	−36	−96	−12	−102	171	−60	−82	−118	96.7
D. B. D.	13.2	17	8	5	−12	−32	−45	−43	13	−30	−12	21.7
D. B. D.	6.0	5	7	26	6	34	−23	4	24	1	17	14.7
D. B. D.	1.9	−66	−11	−178	61	−32	−35	46	7	−10	2	44.8
D. B. D.	0.9	24	122	14	−160	−167	−9	−158	−50	−8	−117	82.9

TABLE II. Localization errors for a frequency of 2000 cycles, expressed in degrees of divergence from median plane fixation.

Subject	Disparity in decibels	Errors in degrees: Number of reading 1	2	3	4	5	6	7	8	9	10	Arith. av.
G. O.	13.2	−15	−20	−46	−17	−31	8	11	−11	19	−40	21.8
G. O.	13.2*	−2	−22	4	−21	−17	−15	−33	−16	−36	−28	19.4
G. O.	6.0	−27	−72	−21	−51	−92	−55	−21	−27	−27	3	39.6
G. O.	1.9	19	−42	31	10	−41	9	−22	25	−24	0	22.3
G. O.	0.9	10	−62	48	44	−63	−37	−20	−29	−42	−41	39.6
G. O.	0.4	−56	111	−142	−66	−92	2	−75	−8	−52	132	73.6
G. O.	0.4*	26	65	−10	18	−51	−108	3	−81	−44	38	44.4
G. O.	0.2	71	134	162	−50	92	−106	3	−150	−21	23	81.2
D. B. D.	13.2	17	−11	10	0	20	21	27	8	9	13	13.6
D. B. D.	13.2*	40	−41	−28	38	5	16	19	35	38	22	28.2
D. B. D.	6.0	29	15	2	2	10	1	34	22	−20	3	13.8
D. B. D.	1.9	0	4	7	26	−38	4	−26	59	−55	−32	25.1
D. B. D.	0.9	−19	−103	20	−42	−14	−8	22	−13	1	48	29.0
D. B. D.	0.4	−96	−134	102	26	112	13	87	−10	152	136	86.8
C. W. B.	13.2	−12	33	12	0	7	−27	1	−16	−16	−25	14.9
C. W. B.	6.0	43	14	38	−10	42	12	2	0	22	27	21.0
C. W. B.	6.0*	34	14	−4	10	18	2	−13	11	−26	−12	14.4
C. W. B.	1.9	−46	152	90	−10	38	34	17	50	54	63	55.4
C. W. B.	1.9*	8	47	62	7	0	42	−3	8	52	40	26.9
C. W. B.	0.9	24	41	1	17	−17	106	17	138	6	−49	41.6
C. W. B.	0.9*	33	−136	−84	−8	−10	−84	−28	−71	−75	−13	54.2
C. W. B.	0.4	−40	−55	53	−5	137	−18	−32	93	11	−15	45.9
C. W. B.	0.4*	−117	−21	−82	−102	−54	−47	−23	−37	−185	−40	70.8
C. W. B.	0.2	−86	−68	−167	−99	−50	−63	−25	−30	−87	−45	72.0

maximum disparity for a complete head rotation was made large, at first, as it would be if the head were *near* a sound source. Ten readings were taken at this setting. Then the maximum disparity was reduced, *as if* the sound had receded into the distance and at the same time had become louder to compensate for the loss of transmission by distance, and ten more readings were taken. Step by step the maximum intensity disparity was thus reduced until average error was between 75° and 90° and numerous front-back reversals began to appear. These failures may be considered, perhaps, to be equivalent to "lapse effects," since every indication of localization disappeared in some of the readings.

The auditory acuity of all subjects had been measured. All had normal hearing for the 200 frequency. All had matched ears. One subject, A. F., had a high-pitch deafness which produced a loss of 10 db for the 2000-cycle frequency. The

stimulus was adjusted to compensate, and his data are similar to the others, except for the fact that his series was not carried to the last step.

The judgments on the first two steps were easily and quickly made, and the subjects were highly confident that they were correct. But when the maximum disparity reached the 1.9-db step the discrimination became extremely difficult, and subjects became slow and loath to make a commitment. They turned their heads back and forth dozens of times, in making one judgment, until they caught a fleeting spatial change in the "sound phantom." In spite of this, there are very few front-back reversals, and there was an average localization better than "chance." When the 0.9-db step was reached subjects still relied on the assurance of the experimenter that there was a disparity really there, and at the 200 frequency struggled in vain to find it, until sheer fatigue made it impossible to take more than ten readings at one sitting.

Table I shows the angular errors for various maximum disparities using the 200 frequency. Left errors are given negative signs; right errors are the positive values. Table II shows the angular errors for various disparities using the 2000 frequency. Figure 3 plots the angular errors against the maximum disparity values from Table I. Figure 4 plots the values from Table II. The heavy continuous line shows our estimated smoothed trend for all subjects combined. The broken line is a locus showing, for each maximum disparity, how many degrees a subject must rotate his head from equality to produce a binaural disparity of 1 db. The tabular db column contains certain positions marked with asterisks; these are repetitions of settings, taken after the initial series, to see if there were *learning effects*. It may, perhaps, be said that there was a slight learning effect, but there were some repetitions where the localization became worse, so the case for learning is not clear.

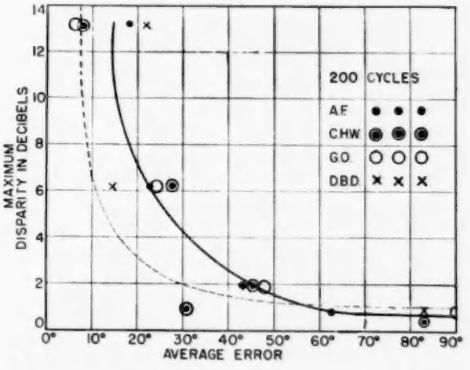


FIG. 3. Average error in degrees of head rotation, for a tone of 200 cycles, plotted against the number of decibels maximum disparity at a given cam-setting. The heavy line gives the approximate trend for all subjects. The broken line shows the number of degrees error of head rotation required to produce one decibel disparity at each cam setting of the apparatus.

For the 200-cycle tone, it appears that reliable discrimination has definitely broken down at 0.9 db. It is definitely better than chance at 1.9 db for all subjects. These values are not far from those obtained by Upton who used a different kind of dynamic progression. There is no evidence for the "lapse effect" at the huge disparities reported by Stewart[6] on *static* stimulus presentations.

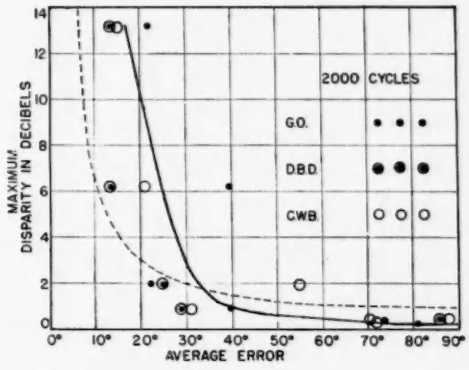


FIG. 4. The data for a 2000-cycle tone plotted as in Fig. 3.

Referring to Table II on the 2000-cycle tone, one of the first items which may strike the reader is the fact that fairly good discriminations were made on the basis of much smaller intensity disparities. Two of the subjects are the same as those used for the 200-cycle tone, so it cannot be a generalized personal difference in using intensity cues. There is no sign of a break at the 0.9-db setting. We could not be certain of the break at the 0.4-db setting, so we tried two runs on the 0.2-db setting, where there was no question but that reliable discriminations were insecure.

The persistent tendency of C. W. B. to show *left* errors cannot be explained with certainty. Such biases have appeared over and over in the

[6] G. W. Stewart, "The intensity logarithmic law and the difference of phase effect in binaural audition," Psychol. Mon. **31**, 30–44 (1922).

past history of binaural localization experimentation. It must be remembered that a pure chance series of ten elements can show freakish distributions. The voltage measurements were repeated carefully and showed no instrumental change. It is admitted that at these very *small* disparity values, perhaps the very slightest difference in pressure on the headphones on the ears would produce mechanical artifacts which were out of our control.

It will be obvious that average angular error, for the first two settings, is equivalent to a disparity of over 2 db when the heavy line is compared with the broken line representing the 1-db position. But when the maximum disparity available is as little as 0.9 db each subject rises to the occasion and shows a discrimination on the 2000-cycle tone which is definitely better than chance. Why? The answer to this may be found in the time required by the subject to make a judgment. When disparities were large, all subjects were confident, rapid, and more or less careless in making judgments. When they began to realize that lesser disparities would be difficult they became correspondingly more cautious. There seemed to be no way of preventing this change in discriminatory *attitude*, or experimental *motivation*. We believe that with an attitude of greater care the discriminations at the 13.2 level could be greatly improved.

The average trend of the very smallest angular errors is surprisingly large in comparison to the errors of localization for sound-cage experiments, commonly known. We have secured pure tone localizations in sound cages with an average error as little as 6° and impure tone localizations with as little as 2° average error. This means that pure tone localizations on the basis of intensity disparity show almost tenfold the size of the errors found under natural conditions. Unless leakage artifacts, under the Wilson and Myers postulate, produce larger intensity errors than we realize, it seems that we must expect that there *must* be some other cue for localization than pure "intensity effect."

Introspective evidence of the subjects verified this conclusion. The localization was always vague at best. At the 13.2 setting one subject said, "I can discriminate the equality position easily enough, but it still doesn't sound as if the tone had a *definite locality*." The author acted as one of the subjects and we can verify the statements of the others. There never was a really convincing localization. D. B. D. said that the illusion of localization *improved* as the experiment went on, but was "unclear" to start with. He finally made the sound appear to be about six feet outside of his cranium. Other subjects could never get the tone to leave the skull, the position merely wagging from near one ear to near the other, as it generally does in binaural beat experiments. This certainly does not leave a convincing impression that all disparity cues can be converted to intensity effects by means of the Wilson and Myers postulate.

A Method for Measuring the Percentage of Capacity for Hearing Speech

EDMUND PRINCE FOWLER
New York, New York
(Received January 31, 1942)

NO two people hear exactly alike even though their audiograms are identical. The mental factor is an integral part of the hearing for all sounds. There are so many variables concerned that even the simplest tests involve very complicated mechanisms. However, as I postulated some four years ago, the following criteria will suffice for setting up a satisfactory method for measuring the capacity to hear air-borne speech:[1]

(1) A hearing test for each ear with a standardized audiometer in a sound-proofed room.[2] This determines the thresholds for the speech frequencies at octave intervals.[3] It does not provide for the relative importance of the different frequencies. It does not show how much speech a person can hear. It really shows only what he cannot hear.

(2) Weighting the frequencies according to their importance for hearing speech. Harvey Fletcher and J. C. Steinberg have used articulation tests of simple words and obtained the following weightings:

Important speech frequencies	250	500	1000	2000	3000	4000	8000
Fletcher weightings	3 percent	7 percent	40 percent	40 percent		10 percent	0 percent
	5	15	20	30		25	5
Steinberg weightings	2	15	20	34		26	3

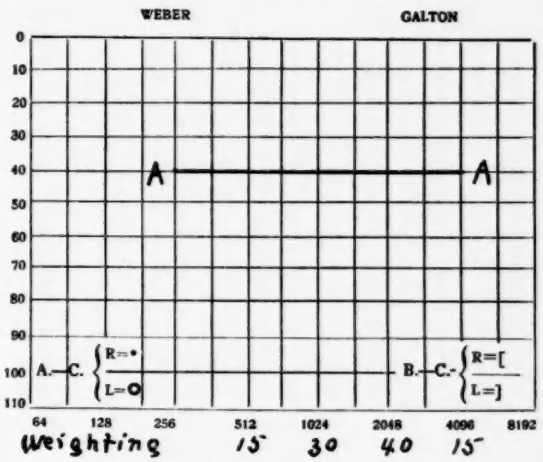
My own data obtained from clinical observations are slightly different from Fletcher's and Steinberg's partly because I have distributed the weighting over seven frequencies (including 3000 frequency) instead of over six. This narrows the gap between 2000 and 4000 and makes for a more complete calculation.

Important speech frequencies	250	500	1000	2000	3000	4000	8000
Fowler complete weighting	3	15	25	30	15	10	2

I have experimented with over twenty different weightings and find that it is possible for our purpose to omit the 256 and 8192 because of their small percentage value, and because they may be merged into the frequencies above and below them, respectively. Doing this and omitting 3000, because most audiometers do not today provide this frequency, I have arrived at the following very easily used weightings for speech (see Figs. 1, 2, and 3):

Most important speech frequencies	256	512	1024	2048	4096
Weightings at four frequencies	0	15 percent	30 percent	40 percent	15 percent
Weightings at five frequencies	3 percent	12 percent	30 percent	40 percent	15 percent

This absorbs the 250 and 8000 frequencies and spreads out the allowance I have given to 3000. These modifications do not change the totals obtained by the former weightings more than a few db except in unusual instances. Using whole numbers and only four frequencies facilitates ease and rapidity of use. This weighting for frequency suffices when deafness is due to an impedance, or obstruction, which prevents the



Obstructive deafness

A

Frequency	Threshold		Wgtd. db loss
512	40	×15 =	600
1024	40	×30 =	1200
2048	40	×40 =	1600
4096	40	×15 =	600
			40.00

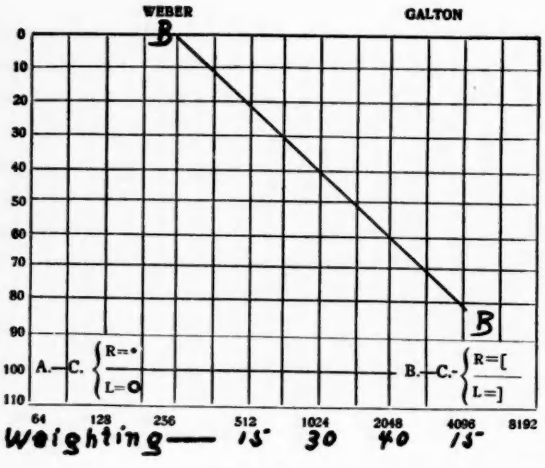
35 percent loss of capacity

FIG. 1. Audiogram of a person with a uniform loss of hearing at all frequencies. (*A*–*A*)

[1] All standards that are set up for the measurement of sensations are more arbitrary than what are called purely physical standards, because the sensation experienced does not always correspond with the degree of stimulation. It is, therefore, necessary to make many observations and to average the data obtained from our physiological and clinical experiments.

[2] The audiometer test is really a refined and accurate substitute for estimating hearing distance.

[3] For a more complete audiogram use one-half octave intervals for the frequencies above 2000.



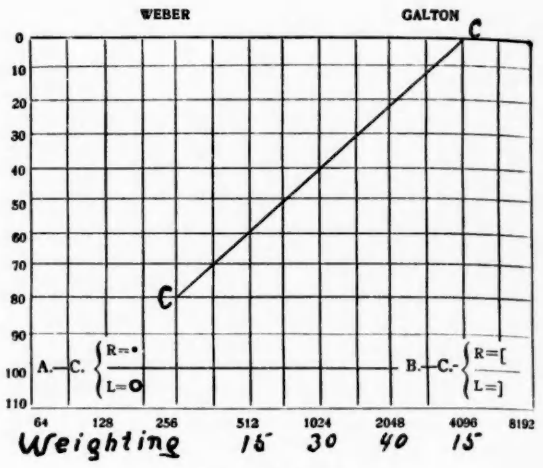
Nerve deafness

B

Frequency	Threshold		Wgtd. db loss
512	20	×15 =	300
1024	40	×30 =	1200
2048	60	×40 =	2400
4096	80	×15 =	1200
			51.00

56 percent loss of capacity

FIG. 2. Audiogram of a person with a hearing loss increasing by a uniform amount at the higher frequencies (*B*–*B*).



Obstructive deafness

C

Frequency	Threshold		Wgtd. db loss
512	60	×15 =	900
1024	40	×30 =	1200
2048	20	×40 =	800
4096	0	×15 =	0
			29.00

19 percent loss of capacity

FIG. 3. Audiogram of a person with a hearing loss decreasing by a uniform amount at the higher frequencies (*C*–*C*).

sound waves from getting into the inner ear, because the improvement obtained from increasing the intensity any distance over threshold is fairly linear.

(3) Allowance for the "recruitment" of loudness phenomenon which always varies in nerve deafness.

(4) A means for estimating the percentage of loss for binaural as well as for monaural deafness. This I have provided for in a table based upon many tests and clinical observations. (See Table I.)

(5) Provision for the changing increments of loss in capacity with slight, moderate, and severe deafness.

The five criteria vary in their importance. I believe that everyone who has given much thought to the subject now concedes the necessity for the audiometer tests and the reasons for weighting frequencies according to their importance in speech, and so I shall devote a few words to the task of explaining why and how much weighting should be allowed for the recruitment of loudness factor and then explain the construction of the table, and its use.

When deafness is due to a loss of function, or response, in the neural elements in the mechanism of hearing, the response for sounds well above threshold (intensities sufficient for intelligibility) is not linear, and so further weighting at the different frequencies is required. This is accomplished by weighting the db loss at each frequency for the recruitment of loudness factor (R.F.) which is the physiological cause of great variations in hearing, for sounds well above threshold. (See Fig. 4.)

The phenomenon of the recruitment of loudness which occurs in all deafness due to a death or loss of response in the neural elements is of primary physiological importance. The neurons in the auditory nerve mechanism function according to the all or none law, like the neurons in any other nerve mechanism. If they react at all, they respond at the optimum. If in the presence of non-functioning neurons the stimulation is sufficiently intense to activate the basilar membrane in areas where neural elements are still available, there is a recruitment of sensation owing to activation of these nerve elements and from other (usually adjacent) areas. Because every fiber is connected to several cells and every cell to several fibers, stimulations well over threshold are sufficient to excite up to

TABLE I. Estimating percentage loss of capacity for hearing speech in monaural and binaural deafness.

Using the table to estimate the percentage of loss of capacity for speech. *Procedure.*—For each ear, multiply the figure indicating the db threshold loss (as shown by the audiogram at each frequency region) by the weighting figures for each frequency.

Frequencies most important for hearing speech	512	1024	2048	4096
Convenient weighting	15 percent	30 percent	40 percent	15 percent

Add the products and divide by 100 (by putting the decimal point two figures from the right). This is the weighted db loss when there is no nerve deafness.

If the B.C. loss is 15 db subtract 6 (the recruitment factor (R.F.)) from the threshold A.C. loss, before multiplying by the weighting figure indicated above at each frequency. For each 5-db loss more than 15 from nerve deafness (or from obstructive deafness) deduct 1 db less (for the recruitment factor) before multiplying by the weighting figure at each frequency. Add the adjusted products and divide by 100. This will give the total weighted db loss.*

Whether or not the frequencies are weighted according to their importance for speech or for the R.F. a percentage of loss of capacity may be obtained from the table as follows: (1) Drop a vertical line from the figure representing the db loss in the better ear. (2) Draw a horizontal line from the figure representing the db loss in the worse ear. The percentage of loss of capacity for hearing speech from monaural or binaural deafness will be found at the point where these vertical and horizontal lines intersect.

Weighted db loss—(better ear)

Weighted db loss—(worse ear)	0	10	20	30	40	50	60	70	80	90	100	Total deafness for speech
0	0%	0	1	5	14	27	44	63	78	89	96	99
10	0	2										
20	1	3	9									
30	2	4	12	20								
40	3	5	14	24	35							
50	4	6	15	27	40	54						
60	5	7	16	29	44	59	71					
70	6	8	17	30	47	63	76	84				
80	7	9	18	31	49	66	80	88	93			
90	8	10	19	32	50	68	83	91	96	98		
Total 100	9%	11	20	33	51	69	85	93	97	99	100%	

Percentage loss of capacity

* If B.C. is normal no weighting is necessary for "recruitment" because there is then no recruitment phenomenon. For threshold losses over 40 db (by A.C. or B.C.) no R.F. weighting is allowed. It is not necessary to figure the R.F. for the worse ear because in this ear it contributes but little to the capacity to hear speech.

the limiting intensity the nerve fibers or nuclei, so that the brain will receive a number of nerve impulses per second approaching and even equaling the number received by a normal ear. This phenomenon operates in all the sensory mechanisms. Its presence is proof positive that the lesion is neural, i.e., a lack of nerve response because of death or preoccupation in the elements concerned. I christened this patho-physiological loudness response "the recruitment phenomenon" (R.F.). This phenomenon occurs at any and all frequencies which show any lack of neural response no matter what other lesions are superimposed (except in total deafness). It enables the person even with severe deafness (60-db loss) to hear sounds which are only 5 or 6 db over this threshold as loud as though they were 30 db over normal threshold. This is only about 35 db below the intensity they are heard by a normal hearing ear, and full 25 db louder than heard by a similar degree (60 db) of obstruction deafness, the exact amount depending upon the degree and type of deafness.

The recruitment in intensity is equivalent to a lessening of obstruction, as shown in the graph.

Ordinary speech is usually heard only when it reaches the ear at least 30 db over threshold, although it can, on occasion, be heard when

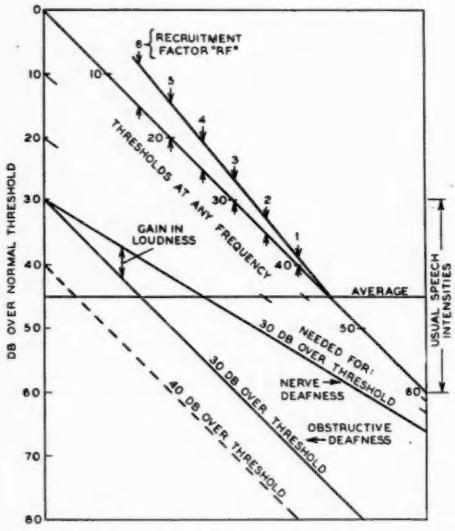


FIG. 4. Gain in loudness due to recruitment phenomenon in nerve deafness and its limitations because of the limits in intensities available for speech.

fainter than this.[4] However, no one usually pays much attention to speech of lesser intensity than 30 db over threshold. This means that for an obstructive deafness of 40 db, speech must reach the ear with an intensity of over 70 db. It means that for a threshold loss of 50 db it must reach the ear with an intensity over 80 db. This latter is equivalent to a loud shouting voice very near the listener. People do not usually speak as loudly as this. However, in nerve (perception) deafness, much less than these increases in intensity is required.

With threshold losses from nerve deafness of 40 db, speech to be satisfactorily heard (30 db over this threshold) need reach the ear with an intensity of only 54 db (14 db over this threshold) to make it seem as loud as 70 db does to an ear with 40 db of obstructive deafness. It shows a gain of 16 db in favor of the nerve deafened ear. It follows, and it is a fact, that some people hear better with a nerve deafened ear than with an obstruction deafened ear, even though the A.C. and B.C. thresholds in the latter case would seem to indicate the better hearing. It accounts for the fact that many people with apparently similar audiograms hear quite differently.

[4] Steinberg's and Gardner's tests show 30 db over threshold produce 70 percent articulation, and this is sufficient for everyday use in the home and business.

These simple illustrations of the difference between the capacity to hear speech of an ear with obstructive deafness as compared with an ear with nerve deafness should be sufficient to prove the necessity of making some allowance for the recruitment factor (R.F.) in estimating the capacity to hear sounds well above threshold.

It must be kept in mind that only sounds well above threshold enable the ear to hear speech so that it is intelligible. Speech frequencies, at or very near threshold loudness, are too faint for interpretation.

The increased capacity enjoyed because of the R.F. is very efficient in the lesser degrees of deafness. In slight deafness (i.e., threshold losses up to 20 db), it practically removes all the handicap of deafness. (See Fig. 5.)

The recruitment phenomenon shows an increasing percentage of loudness, with intensity over threshold, but with a diminishing increment (Fig. 4), and a gradual loss in clarity, so that for losses over 40 db by B.C. at any frequency the gain from the loudness is largely annulled by the loss in clarity. Moreover when there is more than a 40-db loss because of any kind of deafness "recruitment" is of little use, because the threshold is so high that only very loud speech can be heard, unless hearing aids are used. The threshold values as well as the degree of nerve deafness, determine the efficiency of the gain in loudness. However, there is some gain even though the sounds are not above the 30 db threshold level, even $2\frac{1}{2}$ db over will produce a noticeable gain in loudness no matter how small or how great the nerve deafness loss may be.[5]

Coincidental obstruction deafness cannot be entirely ignored as to its affects on recruitment because it elevates the threshold and cuts down by this amount the availability of the R.F. As I said before, speech sounds to be heard at all must be well over threshold. However, the R.F. operates at all degrees of hearing loss and serves as a safeguard, enabling one to hear warning sounds and so guard against accidents, and it also aids in determining the direction of sound

[5] One way to detect the presence of recruitment is to notice whether a patient senses an increase of 5 db in intensity over threshold as a marked change or as only a slight change in loudness. If the testing is expertly done, nerve deafness will cause a marked change, and obstructive deafness only a slight change. (The patient will sense this.)

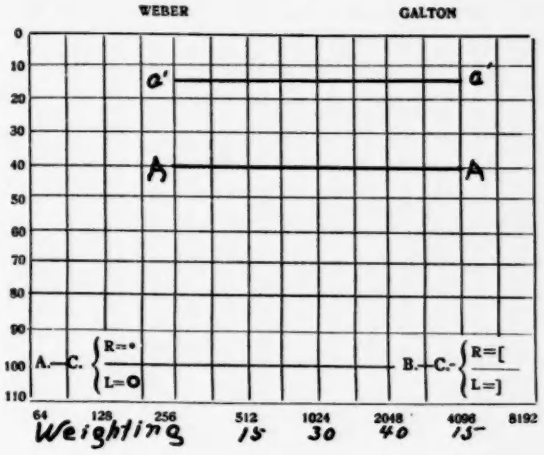
origin (stereophonic effect). It serves to attract attention to the speaker, and therefore in this way it increases, to some extent, the capacity to hear speech. Unless one is aware that someone is speaking, no attention is paid to the speaker. He is not listened to.

Obstruction deafness is a more serious handicap in some particulars than nerve deafness. However, as even severe nerve deafness permits all loud sounds to reach the inner ear, the R.F. operates equally well for the sounds desired and those not desired to be heard. This is one reason why people with pure nerve deafness cannot hear well in a noisy place. (Speech is masked out by the environmental noise.)

Obstruction deafness cuts down undesirable as well as desirable sounds no matter how high the threshold, but because one speaks louder in a noisy place and the environmental noise is not heard, the deafened person is benefited in this way. Man is conditioned early in life to raise his voice in a noisy place (to be heard and to hear his own voice) and to speak louder the greater the distance he is from the person to whom he wishes to speak. These habits of man often mislead us in our judgment as to how well a person is hearing. On the other hand, there is no doubt but that in fairly quiet places (noise not over 30 db) people with moderate nerve deafness (20- to 40-db loss at any or all frequencies) usually hear better than those with obstruction deafness of like degree. I realize that for single words Steinberg and Gardner found little difference in a sound-proofed room in the articulation percentages as between perception and obstruction deafness. Their tests were done under very artificial conditions using telephone and single words. However, they do show a noticeable advantage for nerve deafness over obstructive deafness, for losses less than 40 db. In other words, the percentage of loss is greater than for similar db losses in nerve deafness. My method is designed for measuring the capacity to hear language as it is spoken in everyday life. Man needs only a portion of the pattern of familiar speech to interpret language satisfactorily; he fills in the missing blanks in the jigsaw sound puzzle; he cannot do this very well for single words or monosyllables. He cannot do it if he has not learned to recognize the words.

What allowances should be made for the recruitment factor? My data indicate that 5 or 6 db should be deducted from the A.C. threshold loss if there is a loss of 15 db from nerve deafness, because this loss is fully made up when sounds are well over threshold. This is the least I can allow because if sound is heard at all, it will, 99 times out of 100, be well over threshold. No allowance is made for losses less than 15 db by B.C., because such losses are often due to observational errors.[6] For each additional 5-db loss over 15, deduct 1 db from the R.F. because there is a loss in clarity and because the threshold is raised (i.e., for a 20-db loss by B.C. deduct 5; for a 25-db loss deduct 4, etc.).

As shown in the graph, this allows no benefits from the recruitment of loudness for losses greater than 40 db. For greater losses the table takes care of it in large part because the



Nerve deafness

a'

Threshold	R.F.		Wgtd. db loss	Frequency
15	− 6	=9×15 =	135	512
15	− 6	=9×30 =	270	1024
15	− 6	=9×40 =	360	2048
15	− 6	=9×15 =	135	4096
			9.00	

1½ percent loss of capacity
5 percent if R.F. is not used

A

Threshold	R.F.		Wgtd. db loss
40	− 1	=39×15 =	585
40	− 1	=39×30 =	1170
40	− 1	=39×40 =	1560
40	− 1	=39×15 =	585
			39.00

33 percent loss of capacity
35 percent if R.F. is not used

FIG. 5. The application of the recruitment factor and its effects.

[6] B.C. losses up to 15 db at only one or two frequencies may be due to an observational error. If they occur at three or more frequencies they should be dependable.

thresholds are then so high that the recruitment phenomena have little, if any, beneficial effect unless hearing aids are used to amplify the sound. In fact, even then they may hinder rather than help the hearing for speech.*

In setting up these standards it must be constantly kept in mind that hearing varies tremendously with distance and with environmental noises. For instance, in a noisy place the recruitment phenomena is of no benefit because it makes the environmental noises seem almost as loud as they seem to a normal ear, and sometimes even louder. If one ear is severely or totally deafened, the hearing ear is easily masked out by the noise. In obstructive deafness the masking is more difficult. One of the problems is to estimate what part of a person's time is spent in a noisy place (noise level over 30 db) and in a quiet place (noise level below 30 db). In cities 100 percent may be spent in noisy places. In the country probably only 50 percent is spent in noisy places. Table I takes care of the many factors discussed and much more.

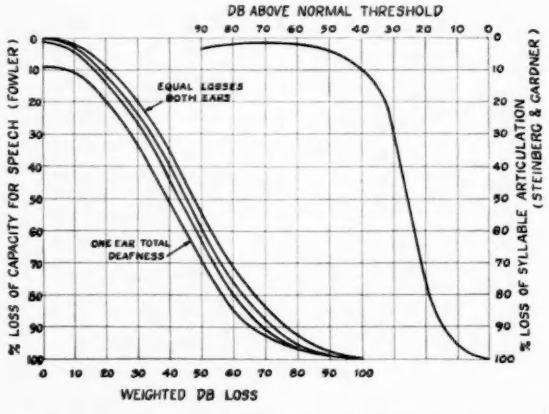

DB ABOVE NORMAL THRESHOLD
90 80 70 60 50 40 30 20 10 0
EQUAL LOSSES BOTH EARS
ONE EAR TOTAL DEAFNESS
% LOSS OF CAPACITY FOR SPEECH (FOWLER)
% LOSS OF SYLLABLE ARTICULATION (STEINBERG & GARDNER)
0 10 20 30 40 50 60 70 80 90 100
WEIGHTED DB LOSS

FIG. 6. Comparison of plot of table for estimating percentage capacity for hearing speech and Steinberg-Gardner articulation *versus* speech intensity curve.

* There is really a reversal in the R.F. in the neighborhood of a 40 db loss by nerve deafness, and the figure representing this reversal should rightly be added at each frequency. It was omitted as a compromise with the opinion that "recruitment" should not enter into calculations. If included the following (R.F.) allowances are indicated. Apply corrections before averaging A.C. losses.

B. C. loss less than				
15	db subtract	0	from	A. C. loss
15	"	5		"
20	"	4		"
25	"	3		"
30	"	2		"
35	"	1		"
40	"	0		"
45	add	2	to	"
50	"	5		"
50+	"	5		"

Below a 40 db loss these figures vary 1 db from allowances discussed in text.

ANALYSIS OF TABLE AND ITS GRAPH

The curves on the left of Fig. 6 show my calculations for percentage of capacity to hear language. For single sounds the data of Steinberg and Gardner (see curve on right of Fig. 6) show the percentage of articulation with varying intensity. These two graphs conform generally, but for spoken language my graph conforms more closely to clinical experience because it was constructed on this basis.

No loss is indicated when the weighted db loss is less than 10 db because clinical tests show that such slight losses are too small for practical use.

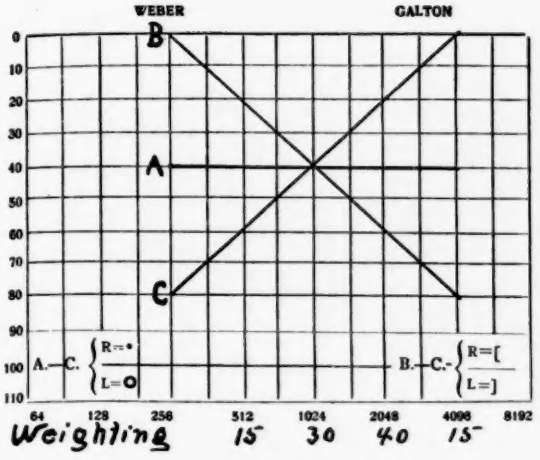
At the present time there is no standard set-up for near hearing distance, medium hearing distance, or far hearing distance. I suggest that five feet or less should be considered *near hearing distance*, from five to fifteen feet *medium hearing distance*, and over fifteen feet *far hearing distance* for conversational speech.

Careful tests in a large office show that on the average employees conversed about 46 percent of the time within five feet. Since this is true, it would appear that if any of these people cease to hear ordinary conversation beyond five feet, he loses fully 54 percent of his opportunities to hear speech.

The tests for the interpretation of speech by the Bell Telephone Laboratories, Newhart and Hardig, myself, and others indicate that with a 50-db loss people are unable to hear moderately loud speech satisfactorily at distances over four to five feet. In Table I a binaural conduction loss of 50 db shows a 54 percent loss of capacity to hear speech. This is taken as the central point of the table. 0-db loss and 100-db loss are the two extremes.

The increment of percentage loss increases up to a 50 weighted db loss in both ears, and up to a 50 weighted db loss in the better ear, no matter how deaf the worse ear (i.e., each 5-db step is 1 percent greater than the preceding 5-db step).

For losses greater than 50 db in both ears, the increment of percentage loss diminishes with increasing deafness except at the extremes of



A Obstructive deafness

Frequency	Threshold		Wgtd. db loss
512	40	×15 =	600
1024	40	×30 =	1200
2048	40	×40 =	1600
4096	40	×15 =	600
			40.00

35 percent loss of capacity

B

Threshold		Wgtd. db loss
20	×15 =	300
40	×30 =	1200
60	×40 =	2400
80	×15 =	1200
		51.00

56 percent loss of capacity

C

Threshold		Wgtd. db loss
60	×15 =	900
40	×30 =	1200
20	×40 =	800
0	×15 =	0
		29.00

19 percent loss of capacity

A Nerve deafness

Frequency	R.F.		Wgtd. db loss
512	40 − 1	=39×15 =	585
1024	40 − 1	=39×30 =	1170
2048	40 − 1	=39×40 =	1560
4096	40 − 1	=39×15 =	585
			39.00

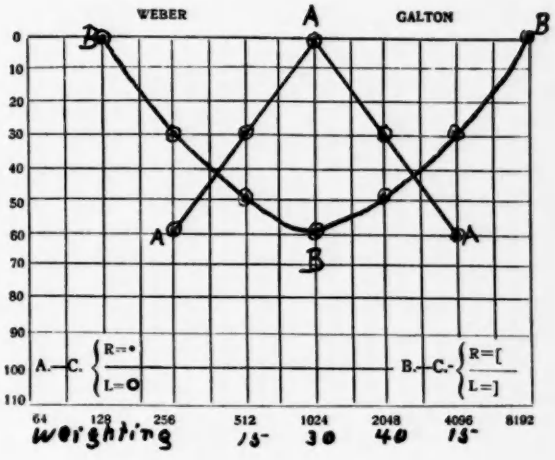
33 percent loss of capacity

B

R.F.		Wgtd. db loss
20 − 5	=15×15 =	225
40 − 1	=39×30 =	1170
60 − 0	=60×40 =	2400
80 − 0	=80×15 =	1200
		49.95

54 percent loss of capacity

FIG. 7. Solution of three theoretical cases, applying the recruitment factor in nerve deafness.



A

Threshold	R.F.		Wgtd. db loss	Frequency
30	− 3	=27×15 =	405	512
0	− 0	= 0×30 =	0	1024
30	− 3	=27×40 =	1080	2048
60	− 0	=60×15 =	900	4096
			23.85	

13 percent loss of capacity

B

Threshold	R.F.		Wgtd. db loss
50	− 0	=50×15 −	750
60	− 0	=60×30 =	1800
50	− 0	=50×40 =	2000
30	− 3	=27×15 =	405
			49.55

54 percent loss of capacity

FIG. 8. Solution of two theoretical nerve deafness cases with irregular audiograms.

the scale (i.e., each 5-db step is 1 db less than the preceding 5-db step).

The percentage loss for the first 10-db difference between the two ears is, except in very slight deafness, always greater than the second or subsequent 10-db differences between the two ears.

Ten-db differences between the losses in the two ears show a progressing increment of percentage loss up to a 40 weighted db loss for the better ear, and over 60 db a diminishing increment of percentage loss, but the percentage loss is always less than a 5-db equal loss in the two ears (except for over 80-db losses).

A 20-db difference between the losses in the two ears shows a percentage loss equal to a 5-db equal loss in the two ears, except when the better ear is down over 50 db (when it is 1 or 2 db greater than the 5-db equal loss).

The increase in percentage loss owing to a total deafness in one ear varies from 9 percent when the hearing ear is only slightly down (not over 15 db) to 16 percent when it is down 40 to 45 db. When down more than this the differences in the increase in percentage loss owing to the total deafness of one ear diminish rapidly. These allowances at first sight may appear too high, but clinical observations of people with hearing in only one ear substantiate them. (Note the hearing distances given on the audiograms displayed at the end of this paper.)

The proportion of time that the sounds one wishes to hear will come from the side of the good ear, or the side of the poorer ear, becomes more and more important as deafness increases. People usually depend on their poorer ear much less than the differences in thresholds indicate. Even a 5-db difference between the two ears

will make it appear as though there was little hearing in the poorer ear. People refer to their poorer ear as "my dead ear." For these reasons a greater percentage of loss is assigned to the first 5-db difference between the ears than to the second 5-db difference. Except for losses of 10 db or less in the better ear, less and less is allowed for the increasing differences between the two ears, because the worse ear, for speech sounds of ordinary intensity, will be less and less important the greater the difference between it and the better ear.

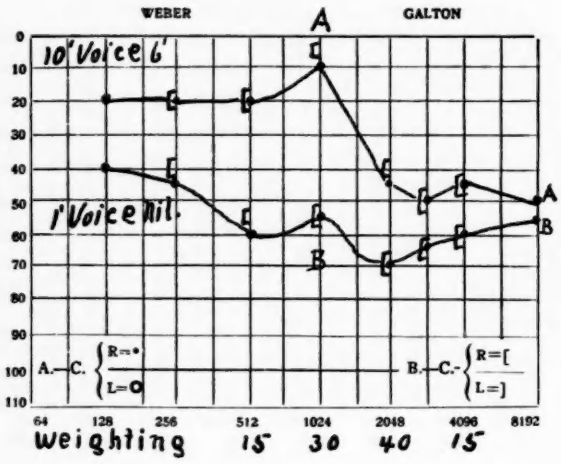
People with losses of 20 db in both ears can hear even the soft voice at 20 feet or more. They have according to Table I a loss of 9 percent. But if one ear is totally deaf, the over-all percentage loss is greater than this, in fact more than double this, or 20 percent. A study of Table I will reveal the changing increments of loss according to the different degrees of monaural and binaural deafness. They appear to agree very closely with the tests of many investigators.

A lone hearing ear is in a position to hear speech about nine-tenths of the time. My observations reveal that except when masking occurs in such a lone hearing ear, even when it is turned directly away from the sound sources, there is a loss in intensity in the sound reaching it of only about 20 db, on the average. It shows that if the hearing ear is perfect, or nearly perfect, the total loss, because of an opposite total deafness, is only about 9 percent, as shown in Table I. However, if the hearing ear is down some 40 or 45 db it is proportionally of less use and so 16 percent is added to the better ear percentage loss, to allow for this increased loss in hearing capacity. For greater losses the increment of percentage loss, because of monaural total deafness, becomes less and less because the rising threshold of the hearing ear rapidly diminishes its availability for sounds coming from the side of the totally deaf, or worse ear.[7]

Whole numbers were adhered to throughout the table to facilitate ease of calculation. This does not usually alter actual calculations more than 1 percent and even in unusual instances more than 3 percent.

I show theoretical (Figs. 7 and 8) and actual (Figs. 9 and 10) audiograms to illustrate my method for determining the percentage of capacity to hear speech. It will be seen that these audiograms cover most of the variations commonly found in people who are hard of hearing. Using the Bunch or Sabine method the percentage of loss assigned to these audiograms in many instances will vary considerably from mine, and will not reflect the true loss of capacity to hear speech. The discrepancies are mainly owing to the fact that they do not make allowances for the great differences which occur with the different degrees of deafness.

In my opinion, of more importance than all the other criteria I have been discussing, is my method of calculating the percentage of loss from monaural and binaural deafness as worked out in Table I. In other words, one would arrive



A

Threshold	R.F.		Wgtd. db loss	Frequency
20	− 5	=15 × 15 =	225	512
10	− 0	=10 × 30 =	300	1024
45	− 0	=45 × 40 =	1800	2048
50	− 0	=50 × 15 =	750	4096
			30.75	

35 percent loss of capacity (opposite ear total deafness)
23 percent if loss in both ears was 31 db

B

Threshold	R.F.		Wgtd. db loss
60	− 0	=60 × 15 =	900
55	− 0	=55 × 30 =	1650
70	− 0	=70 × 40 =	2800
60	0	=60 × 15 =	900
			62.50

88 percent loss of capacity
74 percent if loss in both ears was 62.50 db

FIG. 9. Solution of two audiograms of the same ear measured at different times—other ear totally deaf.

[7] It is not necessary to figure the recruitment factor for the worse ear, because in this ear, it contributes but little to the capacity to hear speech.

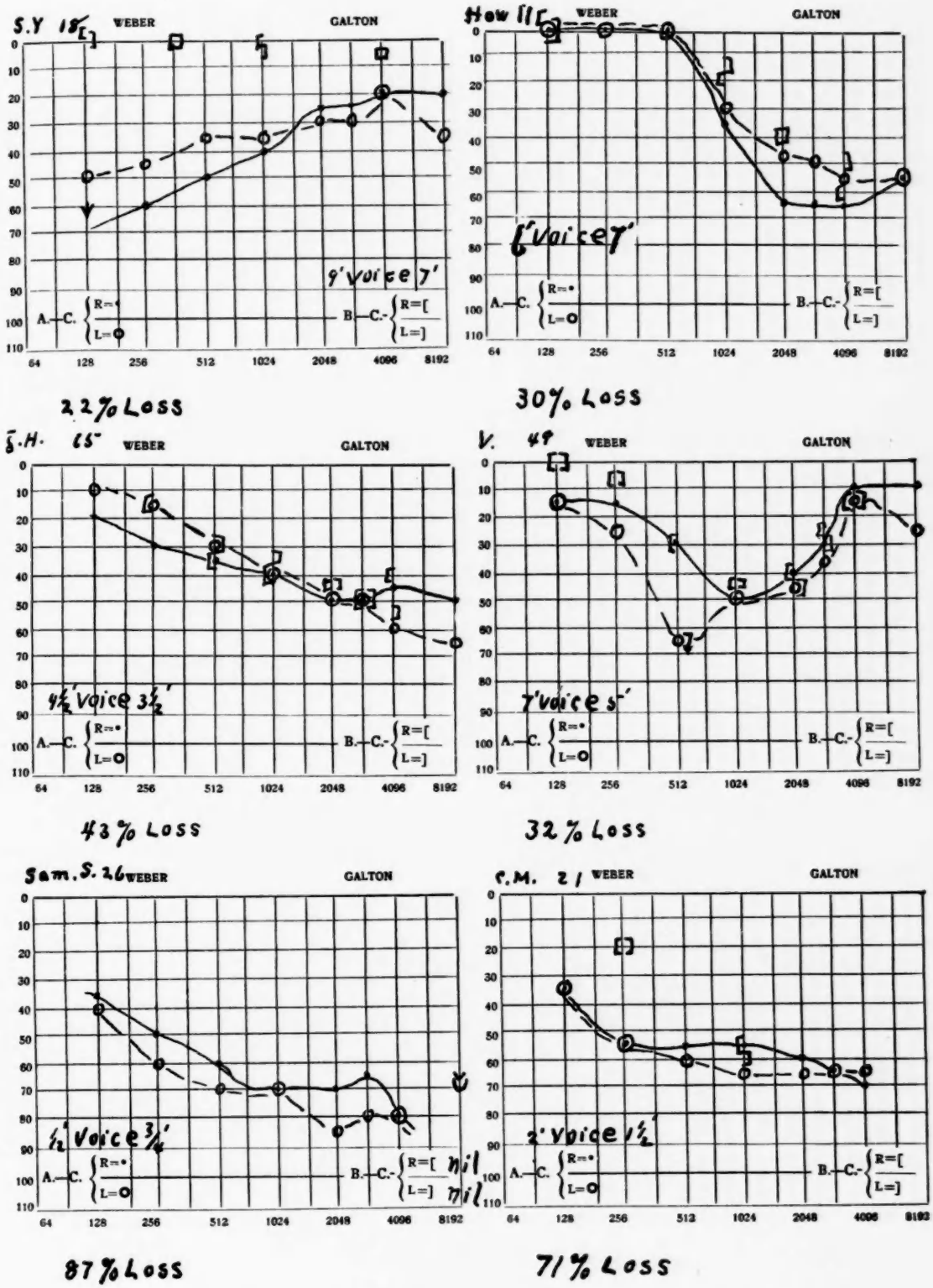


FIG. 10. Typical audiograms and calculated percentage loss in capacity. Hearing for the soft conversational voice also shown.

at a fairer estimate by using the table and ignoring the R.F. and the weightings for speech than by using either or both these weightings and not using the table.

SUMMARY

The method I have described takes care of the five important criteria for estimating the capacity for hearing language, as follows:

(1) Hearing distance, by threshold audiograms.

(2) Differences in importance of the frequencies for hearing speech, by properly weighting the db loss at each frequency.

(3) The recruitment phenomenon which always occurs in nerve deafness and which accounts for the differences in hearing capacity with similar threshold losses in obstructive and nerve deafness, by weighting for the "recruitment" factor (R.F.) at each frequency where it is operative.

(4) Binaural as well as monaural deafness by means of allowances based on many tests and clinical observations.

(5) The increasing and diminishing increments of capacity to hear speech according to the slight, medium, and severe degrees of deafness, by means of calculations contained in a table based upon careful clinical observations and laboratory tests. The two most important and dependable criteria are the threshold audiograms and the calculations set forth in Table I. If these two are chosen, then the method of using Table I is very simple indeed. Determine the average db loss for both ears (using the frequencies most useful for speech), and drop a vertical line from the db loss figure of the better ear, and draw a horizontal line from the db loss figure of the worse ear. The percentage loss will be at the point where these two lines meet.

Experiments on the Pellet-Type of Artificial Drum*

KARL LOWY
University of Rochester, Rochester, New York
(Received December 20, 1941)

WHEN hearing is impaired because of loss of part of the sound-conducting mechanism of the middle ear, it can sometimes be improved by inserting foreign bodies into the tympanic cavity. This knowledge can be traced back to the seventeenth century. It is customary to call anything which, when applied to an open middle ear cavity, improves hearing, an artificial drum membrane (A.D.). This expression is misleading because it rarely is a membrane and almost never replaces the original drum. Since the name is, however, adopted by most authors, we shall use it in this paper.

A great variety of A.D.'s has been employed. Most commonly used is the plain cotton pellet, because it requires no special apparatus and can easily be replaced by a doctor or trained patient. Although it may not be the best possible form of A.D.,[1] it deserves a more thorough consideration because it often works satisfactorily.[2]

The application of the A.D. and its effect can best be described by a typical case history: F.Ch., 39 years of age, otitis media chronica left; almost total destruction of the drum membrane, promontorium epithelized, remnant of malleus and head of stapes visible. Hearing: Whispering voice = 0, conversational voice = 10 cm. A small cotton pellet is sterilized over a flame, dipped into sterile mineral oil and placed between head of the stapes and posterior bony wall of the external meatus under slight pressure. Hearing after insertion: Whispering voice = 20 cm, conversational voice = 50. The audiogram is given in Fig. 1.

The improvement is considerable even for high tones, a fact already stressed by Nadoleczny.[2] Some authors (see Tamari,[3] Fig. 4, and Békésy[4]), however, find the A.D. effective only in the lower range of the auditory spectrum. We shall later discuss the possible cause of this discrepancy. In Fig. 1, there is also a slight improvement of bone conduction; this should not be considered a typical result since it is absent in many cases.

Many attempts have been made to explain the action of the A.D., of which we shall mention only a few (cf. Peltzer's[2] article for additional references). Toynbee[5] thought that the intact middle ear cavity concentrated the sound on the round window, which became impossible when the drum membrane was destroyed. Lucae[6] proposed three different explanations. At first he advocated increased intralabyrinthine pressure. Later he claimed that the A.D. partly replaced the action of the tensor tympani and thus counteracted traction by the stapedius muscle, thereby improving hearing. He also mentioned the fact that hearing is sometimes improved if the cotton pellet does not touch the stapes, but only the promontorium. In these cases Lucae believes that the cotton prevents direct action of the

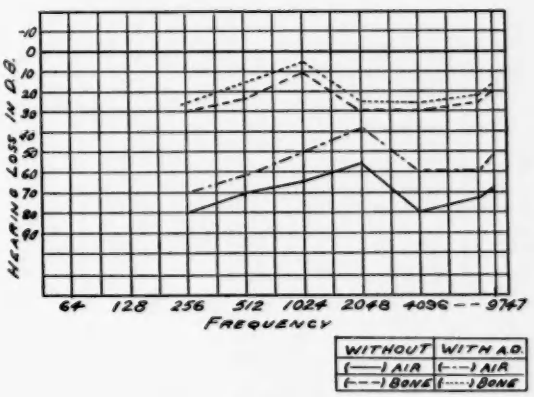


FIG. 1. Effect of A.D.

* Communication No. 42, prepared under the direction of Elmer A. Culler, from the Animal Hearing Institute, Laboratory of Psychology. This Institute is maintained by aid of the Research Council, American Otological Society.

[1] A. G. Pohlman, J. Acous. Soc. Am. **8**, 112 (1936).

[2] In this paper we shall deal only with the pellet-type of A.D. For a discussion of the materials used for this purpose and the methods of application, see A. Politzer, *Lehrbuch der Ohrenheilkunde* (Stuttgart, 1908). A complete bibliography up to 1926 is contained in F. Peltzer, Arch. f. Ohrenheilk. **114**, 198 (1926); additional papers up to 1934 are covered by M. Nadoleczny, Zeits. f. Hals-etc. Heilk. **35**, 472 (1934).

[3] M. Tamari, Wien. med. Wschr., p. 1955 (1931).

[4] G. v. Békésy, Akustische Zeits. **1**, 13 (1936).

[5] J. Toynbee, *On the Artificial Membrana Tympani* (London, 1832) (quoted from Peltzer).

[6] A. Lucae, Arch. f. Ohrenheilk. **54**, 268 (1901). Also, *ibid.* **58**, 142 (1903).

FIG. 2.

sound waves on the bone, thus counteracting interference and enhancing the effect of air conduction. Politzer,[7] agreeing with Lucae, thinks that the pellet, by increasing the surface of the stapes, enhances the force of vibration. Panse[8] distinguished between artificial drum membrane, namely, an apparatus to cover or replace a defective membrana tympani, and artificial operculum. The latter name refers to any intratympanal apparatus of the pellet type which does not really replace the membrane. Panse doubts that increased intra-labyrinthine pressure is a cause of hearing-improvement since that effect could be only temporary owing to escape of perilymph through the perilymphatic duct. He thinks sound can be admitted either through the oval or round window. If both are equally exposed to the sound wave, hearing is impaired; but if one is protected by the artificial operculum, the sound-vibration is more readily admitted through the other window thereby improving hearing. Bárány[9] adopts Panse's point of view and tries to prove it by using a drop of mercury as A.D. in a patient after total mastoidectomy. When the drop covered the round window hearing was greatly increased; but as soon as it was removed, the effect disappeared. Tamari[4] tested hearing in patients who used an A.D. with the "Otoaudion," one of the first audiometers in Europe. As already mentioned he found improvement for low tones and explained it partly by increased mass. Nadoleczny stresses high-tone gains and finds that the A.D. sometimes improves tinnitus. Pohlman,[10] who contends that the normal middle ear mechanism acts as an impedance-matching transformer, is inclined to assume a similar function for the cotton pellet. He has also invented a very effective middle ear prosthesis,[1] upon which we hope to report in a subsequent paper.

Clinical experience alone does not give adequate material for theoretical interpretation of the effect of the A.D. Changing of the pellet, if performed too often, is an irritating manipulation and renders exact audiometry rather difficult. The idea of testing the action of the A.D. with the electrical method in animal experiments was therefore rather obvious.

EXPERIMENTAL PROCEDURE

Sixteen cats were used in the experiments. Operation: nembutal anaesthesia. One cochlea is destroyed. The pinna of the other ear is removed. The bulla is opened by dorsal approach; the posterior wall of the external meatus and the bone separating the middle ear from the bulla are completely removed. Malleus and drum membrane are taken out. Removal of part of the lateral wall of the epitympanic cavity and of the overhanging bone above the round window results in the exposure of the facial nerve, which is severed to interrupt the innervation of the stapedius muscle. The incus is carefully separated from the stapes and removed. The tensor tympani muscle is scraped from its bony support with a small curette. The periosteum about the round window is removed with a small periosteal elevator. Stapes and round window are now well exposed (see Fig. 2). A very shallow pit is drilled in the bone of the promontorium about one and a half millimeters posteriorly to the round window. It is used for insertion of the active electrode and prevents the latter from slipping.

The sound source is a loudspeaker, whose acoustical output is known in absolute quantities and which is connected with the animal's ear through a sound tube and energized by oscillator

[7] A. Politzer, Wien. Medizinalhalle (1864) (quoted from Peltzer).
[8] R. Panse, *Die Schwerhoerigkeit durch Starrheit der Paukenfenster* (Jena, 1897).
[9] R. Bárány, Wien. klin. Wschr., p. 757 (1910).
[10] A. G. Pohlman, Acta otolar. **26**, 162 (1938).

and amplifier. Cochlear potentials are determined with the active electrode on the promontorium as indicated above, the indifferent electrode being attached to the skin. The amplified potential is filtered and measured with a General Radio 636A wave analyzer. For bone conduction a Western Electric receiver was used. Since this generates a powerful electromagnetic field, it was mounted outside the test room and connected with the animal's head by means of a thin brass rod. This set-up proved very satisfactory with no interference from air-borne sound or from electric fields. The brass rod was anchored under moderate pressure to the receiver by a layer of Bakelite and its tip attached to the exposed bone above the auditory meatus. The bone conduction receiver is not calibrated but generates reproducible sound intensities.

Experiment 1

The cochlear audiogram for 4 frequencies (250, 500, 1000, and 4000 cycles) was first determined. A cotton pellet, rather firm and just big enough to cover the oval window, was then dipped into mineral oil and inserted between the stapes and the edge of the upper bony wall of the external meatus, and the active electrode was left in place during this procedure. The A.D. has to be applied under slight pressure. The audiogram was then repeated and the *change in hearing* computed in decibels. The result can be reproduced several times if proper care is taken to remove all the fluid from the oval window after the A.D. has been taken out. The mean values (increase in hearing) from 8 cats are shown in Fig. 3. The standard error (computed by the usual formula, $\sigma/\sqrt{N}$) of the mean improvement for the *highest* intensity at each frequency, and the corresponding p value, are given in Table I.

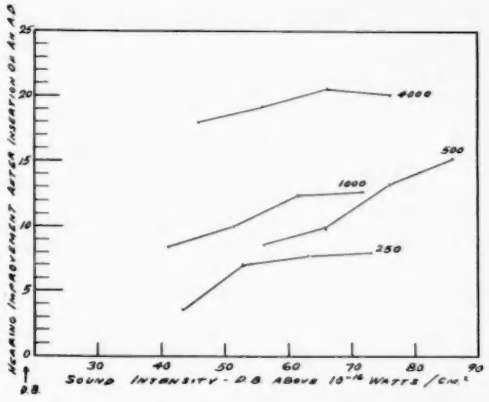


FIG. 3.

TABLE I.

Cycles/sec.	250	500	1000	4000
db	8.0±1.4	15.2±3.5	12.9±2.9	19.2±2.4
p	99.9 percent	99 percent	99 percent	99.9 percent

In the computations, methods appropriate for small samples were used.[11]

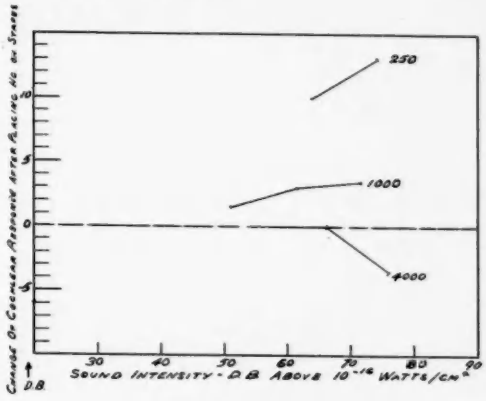


FIG. 4.

The high values of p indicate that the improvement in hearing is unquestionably significant. It extends throughout the entire range tested, being greater at the higher frequencies.

Experiment 2

Bone conduction was tested before and after insertion of a cotton pellet between stapes and the edge of the bone, conditions being the same as in Experiment 1. The mean change in db for 5 cats at 3 different frequencies is given in Table II.

TABLE II.

Cycles/sec.	250	1000	4000
db	+2.5	+.9	+.7

Statistical analysis reveals that the mean change in no case differs significantly from zero. Bone conduction therefore was unaffected by the A.D.

Experiment 3

Instead of a pellet, a small drop of mercury was put into the oval window to cover the stapes.

[11] Cf. L. H. Tippett, *Methods of Statistics*, second edition, Chap. 5.

A curve, showing the mean change for air conduction in 6 cats, is given in Fig. 4. The significance of these values for the *highest* intensity at each frequency is seen from Table III, which

TABLE III.

Cycles/sec.	250	1000	4000
db	13.2±4.6	3.5±3.0	−3.4±1.3
p	95 percent	60 percent	95 percent

gives standard errors and *p*'s for three different frequencies. A comparison of the figures for these frequencies suggests the following inference. Hearing for lower tones is improved by a drop of mercury placed on the stapes; but this effect gradually decreases at higher frequencies and even becomes negative at 4000 cycles. Still better evidence for this differential effect at low and high frequencies is obtained by statistical comparison of the db values for 250 and 4000 cycles. The difference between these two means is, from Table III, 16.6 db; the *p* value being in this case 99 percent, the difference may be considered real.[12]

Experiment 4

Bone conduction was measured in 6 cats with the same set-up as in the previous experiment. The respective values are given in the following Table IV:

TABLE IV.

Cycles/sec.	250	1000	4000
db	13.6±4.8	3.8±1.7	−5.8±2.0
p	95 percent	90 percent	95 percent

Figures and interpretation are substantially the same as in Experiment 3. Again, the difference between the db-change at 250 and at 4000 cycles (19.4 db) is significant with a reliability of 99 percent.

Experiment 5

A drop of mercury, small enough to touch the membrane, was put on the *round* window, and the response to air-borne sound then determined.[13] The average curve for three frequencies in 2 cats is reproduced in Fig. 5 (the letters "r.w." signify "round window"). The result is in line with Experiment 3, although the impairment for high tones is more pronounced.

DISCUSSION OF THE RESULTS AND THEORETICAL REMARKS

Experiment 1 confirms the results obtained from human audiograms: The cotton pellet, placed on the stapes under moderate pressure, improves hearing of air-borne sound. The response to high tones is more improved; a fact which in man is of practical importance for the understanding of speech.

In order to evaluate the other experiments it seems desirable to review some theoretical concepts concerning the operation of the A.D.

Panse's and Bárány's "screening" theory seems to be the most acceptable. Consider the ear after the removal of the drum, malleus and incus, which we shall call a "reduced ear." Let P_0 be the sound pressure exerted on the oval window, P_r the pressure acting on the round window. On account of the smallness of the inner ear (compared with the wave-length) both will be in about equal phase. The entire sound pressure P, acting on the reduced ear will then be $P_r - P_0$. The pellet, covering the stapes completely, will reduce P_0 to P'_0 ($P'_0 < P_0$) while P_r remains unchanged. Sound pressure on the reduced ear will then be $P' = P_r - P'_0$. Since $P' > P$, sound intensity is increased.

According to this theory, improvement over the entire frequency range should be expected for air-borne sound, but not for bone conduction because in this case sound is not admitted through the windows. Actually, bone conduction is almost unchanged after the insertion of the cotton pellet, as seen from Experiment 2.

So far, Bárány's theory is satisfactory. The fact, however, that the A.D. is more effective for higher frequencies remains to be explained. The following argument on the acoustical properties of the reduced ear may be found helpful, although it has to be based on simplifications. Regard the reduced ear as a vibrating system of one degree of freedom with mass (m), friction (r), and stiffness (s). Placing a small piece of cotton on the stapes, under slight pressure will considerably increase stiffness whereas we may assume that mass and friction will remain virtually unchanged. It is shown in the appendix that under these circum-

[12] Reference 11, p. 115.

[13] This is not a duplication of Bárány's classical experiment, because there was no layer of air between metal and round window.

stances response to tones *above* the original resonance-frequency should be increased, and to lower tones should be decreased. Together with a general increase, due to the screening effect, this would account very well for our experimental results.

To check this explanation, we consider the effect of increased *mass* on our system. If mercury is put in direct contact with the head of the stapes, or applied directly to the round window membrane, a considerable increase of mass results whereas the effect on friction and stiffness should be much less. It can be demonstrated (see Appendix) that under these conditions response to tones *below* resonance-frequency should be increased while high tone response should be impaired. This is actually found in Experiments 3 and 5. The fact that there is no evidence of a "screening" effect in either case can be easily explained: The mercury drop was too small to shield the round window membrane but still had the effect of weighting the vibrating system. In Experiment 3, also, we were more concerned with direct contact between stapes and mercury than with complete obstruction of the oval window. Consequently, some high-tone loss could be expected. Experiment 4 shows that the change for bone conduction is about the same as that observed for air conduction, if mercury is used; this is another evidence for the fact that the effect of increased *mass* should be distinguished from that of increased stiffness.

In practical otology the pellet used is sometimes rather big. If an A.D. of considerable size just touches the round window membrane or bone, without exerting any elastic pressure, then its action is more likely to be due to increased mass rather than increased stiffness. Low-tone improvement should then be expected, as was actually observed by Tamari and Békésy.

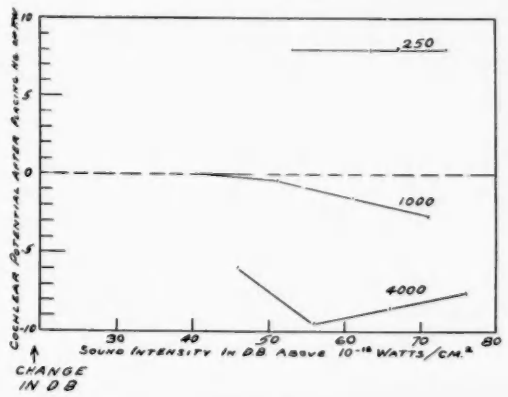


FIG. 5.

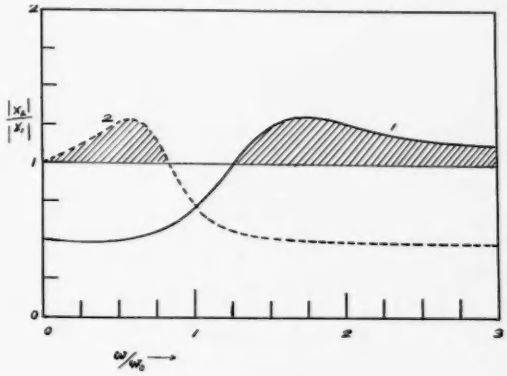


FIG. 6.

SUMMARY

1. The pellet-type of artificial drum, if placed on the stapes under slight pressure, improves hearing throughout the practical hearing range, especially for high tones. This is of importance for the understanding of speech.

2. The mechanism of action seems to be composed of two effects: *screening* and *increased stiffness* of the vibrating system. Under these circumstances bone conduction remains virtually unchanged.

3. Increased *mass* of the vibrating system produces low-tone improvement and (in absence of the screening effect) high-tone loss. This phenomenon can be demonstrated by weighting the system with a drop of mercury.

APPENDIX

Response to increased stiffness or mass of a simple vibrating system. The differential equation of the system is:

$$m(d^2x/dt^2)+r(dx/dt)+sx=F=F_0e^{j\omega t}$$

where

m = mass,
r = resistance,
s = stiffness,
F = force acting on the system,
F_0 = its amplitude,
$\omega=2\pi f$,
f = frequency in c.p.s.,
x = displacement.

The stationary state solution is:

$$x=x_0e^{j\omega t}.$$

Let the auditory stimulus be represented by the displacement x. We then have

$$x(-m\omega^2+j\omega r+s)=F,$$

or

$$x=F/[(s-m\omega^2)+j\omega r].$$

The ratio of two different displacements (x_1, x_2) for two different sets of constants (m_1, r_1, s_1, and m_2, r_2, s_2) under action of the same force, is

$$x_2/x_1=[(s_1-m_1\omega^2)+j\omega r_1]/[(s_2-m_2\omega^2)+j\omega r_2]$$

or, retaining only the amplitudes

$$\frac{|x_2|}{|x_1|}=\left[\frac{(s_1-m_1\omega^2)^2+\omega^2 r_1^2}{(s_2-m_2\omega^2)^2+\omega^2 r_2^2}\right]^{\frac{1}{2}}. \tag{1}$$

This formula gives the ratio of response for two different sets of constants. We compute two cases, choosing very simple constants, and being well aware that these are only examples and not actual magnitudes.

Case (1): *Only stiffness increased, mass and friction remaining constant.*

Assume:

$$r_1=1, \quad m_1=1, \quad s_1=1;$$
$$r_2=r_1=1, \quad m_2=m_1=1, \quad s_2=2s_1=2.$$

Substituting these values in (1), we obtain:

$$\frac{|x_2|}{|x_1|}=\left[\frac{\omega^2+(\omega^2-1)^2}{\omega^2+(\omega^2-2)^2}\right]^{\frac{1}{2}}.$$

The values computed from this formula are represented by curve 1, Fig. 6. The ordinate indicates the ratio of amplitudes, the abscissa, the frequency expressed as a ratio of the original resonance-frequency. There is gain for higher, loss for lower tones.

Case (2): *Let the mass be increased, stiffness and friction remaining unchanged.*

Set:

$$r_1=1, \quad m_1=1, \quad s_1=1;$$
$$r_2=r_1=1, \quad m_2=2m_1=2, \quad s_2=s_1=1.$$

Formula (1) then yields:

$$\frac{|x_2|}{|x_1|}=\left[\frac{\omega^2+(\omega^2-1)^2}{\omega^2+(2\omega^2-1)^2}\right]^{\frac{1}{2}}.$$

The result is plotted in curve 2, Fig. 6, and shows low-tone gain, high-tone loss.

The Change of Phase Caused by Impedance Deafness*

KARL LOWY
University of Rochester, Rochester, New York
(Received December 24, 1941)

WHEREAS the most important path of sound transmission of the inner ear leads through drum membrane, ossicles, and oval window, the route through the round window is of special importance in certain cases of middle ear pathology (defective chain of ossicles, otosclerosis).

Békésy[1] assumed that prevalence of the conducting function of the round window leads to a reversal of phase of the vibrations within the inner ear, because the basilar membrane is under those conditions moved in the opposite direction. He tried to prove this by an experiment making use of "Drehtoene." If a pure tone is conducted to one ear, and a second tone of very nearly equal frequency and intensity to the other ear, a sensation of *one* tone, shifting its position in space in a horizontal plane, is elicited. The person tested can easily point out the imaginary position of the sound source and its movement. If the same experiment is performed on a person whose one ear is normal, while the chain of ossicles of the other ear is interrupted, the direction of the sound source deviates by approximately 180 degrees from that indicated by a normal person. As soon as the middle ear defect is partly repaired by a cotton pellet, the deviation disappears. Assuming that the localization of the imaginary sound source depends on a change of phase, Békésy takes this as a proof of his hypothesis.

A few years ago, Pohlman[2] raised an important objection to Békésy's assumption. It is known that in otosclerosis deafness is mainly caused by a gradually increasing immobilization of the stapes foot-plate in the oval window; this affects the hearing mechanism in a manner similar to that which results when the ossicular chain is interrupted. Pohlman contends that, if phase reversal actually occurred, there should be a moment in the case history of every otosclerotic patient when the effect of oval and round window would cancel each other, with complete deafness as the result. Later, hearing should partly return, with the inner ear functioning in phase opposite to normal. However, although the course of otosclerosis is very slow, usually extending over decades, transitory complete deafness with spontaneous improvement, as should be expected according to this theory, has never been observed.

This discrepancy seemed to make an experimental study of the problem desirable. It was, therefore, attempted to record and compare in animal experiments the phase relation between the electrical cochlear response before and after interference with the sound conducting mechanism.

METHOD AND RESULTS

The experiments were done on nine cats. The animals were anesthetized with nembutal. One cochlea was destroyed, the other pinna was removed and the bulla opened by dorsal approach. A small hole was chiselled in the lateral bony wall of the middle ear, without removing the inner periosteum. A shallow pit was drilled in the promontorium, posteriorly to the round

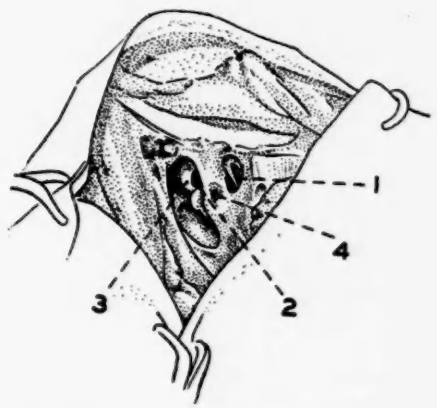


FIG. 1. 1. Drum membrane and malleus; 2, round window; 3, position of active electrode; 4, hole in lateral wall of the middle ear.

* Communication No. 43, prepared under the direction of Elmer A. Culler, from the Animal Hearing Institute, Laboratory of Psychology. This Institute is maintained by aid of the Research Council, American Otological Society.

[1] G. v. Békésy, Akustische Zeits. **1**, 13 (1936).

[2] A. G. Pohlman, Acta otolar. **26**, 162 (1938).

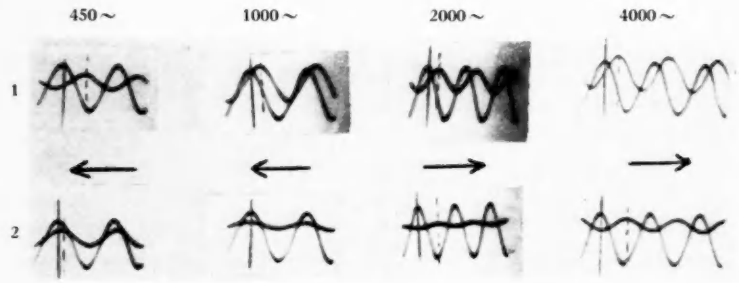


FIG. 2. Air-conducted sound. (1) Middle ear empty; (2) middle ear filled with fluid.

window, for insertion of the active electrode. (See Fig. 1.)

Sound is generated by a heterodyne oscillator, amplifier, and loudspeaker, and transmitted to the animal's ear by means of a sound tube. The active electrode is placed on the promontorium as described above, and the indifferent electrode is attached to the skin. The cochlear potential is amplified, filtered, again amplified, and led through a 185 Dumont electronic switch to an oscillograph. This set-up provides a second channel which is used to record the potential from a crystal microphone, placed near the animal's ear, and generating a reference wave. The phase relation between cochlear response and microphone potential can thus be easily observed and photographed. During the experiment, the position of the microphone is not changed. The procedure of comparing cochlear oscillograms with those obtained from a microphone has been used by several authors.[3, 4]

In one series of experiments we tried to obtain partial immobilization of the ossicles by filling the middle ear cavity with mineral oil. This can easily be done with a hypodermic needle and syringe, through the hole in the bony middle ear wall. The fluid level within the tympanic cavity can be observed through the drum membrane. The motility of the round window is not interfered with by this procedure, and the sound conduction via fenestra rotunda consequently remains unaffected. During the experiment the electrodes are left in place and the sound generator kept functioning, so that any change in phase, if sufficiently great, can be seen directly. Also gross changes in amplitude are, of course, observable.

All the experiments of the first group had this result: Filling the middle ear partially with fluid, as described above, does indeed produce a phase change in the cochlear response, but the nature of the change proved to be different from the anticipated effect. According to Békésy's assumption, we should expect to find a gradual decrease in amplitude, its transition through zero, and, eventually, the negative amplitudes which constitute phase reversal. What actually happens is this: a gradual decrease in amplitude and, concurrently, a *gradual* shift in phase. At no time does the amplitude pass through zero. This behavior probably accounts for the clinical observation that in immobilization of the stapes, temporary complete deafness with spontaneous improvement is never found.

In Fig. 2 the change in both phase and amplitude, resulting from filling the middle ear with oil, can be seen from oscillograms for four different frequencies. The larger wave is the reference wave (generated by the microphone), the smaller one represents the cochlear potential. The phase shift can be seen by comparing the distance between two consecutive peaks of the

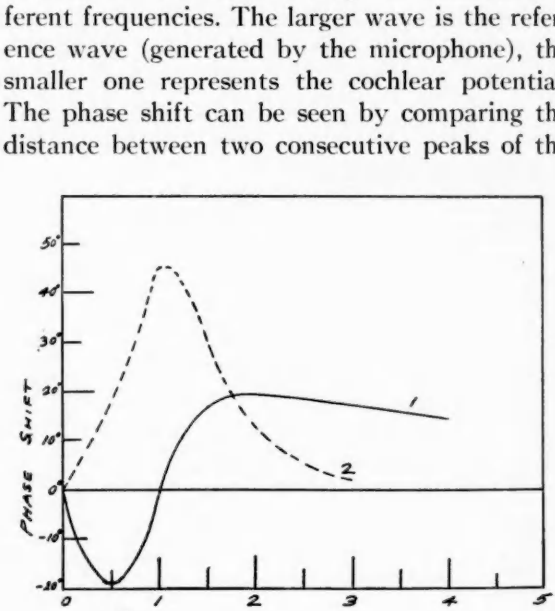


FIG. 3. (1) Phase shift on increase of friction—1 : 2; (2) phase shift on increase of stiffness—1 : 2.

[3] H. Davis, A. J. Derbyshire, M. H. Lurie, and L. J. Saul, Am. J. Physiol. **107**, 311 (1934).

[4] C. S. Hallpike, H. Hartridge, and A. F. Rawdon-Smith, Proc. Phys. Soc. **49**, 190 (1934).

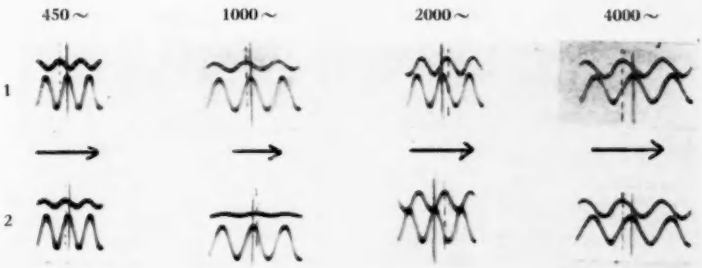


FIG. 4. Air-conducted sound. (1) Normal middle ear; (2) pressure applied on drum membrane.

reference and cochlear waves, respectively, before and after the introduction of fluid. The solid vertical line indicates the phase of the microphone wave, the dotted line of the cochlear wave. The direction of the phase shift is shown by arrows. It varies for different frequencies. Shift to the left denotes lagging phase, shift to the right, leading phase. This was determined by observing the movement of the reference wave as the microphone was moved to and from the sound source; the latter, of course, caused a lag in phase.

The direction of phase shift was the same for each individual frequency in every animal tested. This calls for some sort of theoretical understanding of the phenomenon. An accurate acoustic analysis of middle and inner ear mechanism is too complicated to be attempted; but it may be of interest that, by using a far-reaching simplification, a qualitative acoustical analogy showing the same type of phase shift can be derived. Consider a vibrating system of one degree of freedom with three constants (mass, friction, and stiffness). This system responds to a sinusoidal force with a sinusoidal displacement. It can be shown (see appendix) that change of one of the constants suffices to cause a phase shift of the response. If friction alone is increased (the other two constants remaining unchanged) there is lag in phase below resonance frequency and lead in phase above it. This is shown by curve 1 in Fig. 3. The ordinate indicates the phase shift in degrees, the abscissa, the frequency expressed as a ratio of the original resonance frequency, on the assumption that the friction of the system is doubled.

The phase shift of the cochlear potential upon injecting fluid into the middle ear is qualitatively the same as that which occurs in a simple vibrating system if friction is increased without significant change of the other two constants. Assuming that the mechanism underlying both phenomena is essentially the same, we would conclude that the natural period of the cat's ear is between 1000 and 2000 cycles, which is in agreement with results obtained by more accurate methods.[5]

It has to be borne in mind that this interpretation can only be approximately correct. Injecting oil into the middle ear certainly causes some change of stiffness and mass, although the increase in friction may be of a higher order of magnitude because the ossicles then vibrate in fluid instead of air. Comparing the structures of middle and inner ear with a simple vibrating system, furthermore, is only permissible as a first approximation.

If, in a vibrating system with one degree of freedom, *stiffness* alone is increased, the periodical displacement, which results from the action of a sinusoidal force, instead of lagging below resonance-frequency, as in the previous case, will advance at all frequencies. Curve 2 in Fig. 3 illustrates the effect on phase when stiffness is doubled. Studying the effect of increased stiffness in the animal experiment is difficult because it is hard to avoid simultaneous changes in mass. We tried, however, the following experimental set-up: a light dental pledget was attached to the tip of a thin piece of tungsten wire. This little instrument was pressed against the malleus through the meatus by means of a micromanipulator. This arrangement enables us to exert a constant pressure of variable intensity on the chain of ossicles without changing the friction or mass of the system too much. The effect is seen from oscillograms reproduced in Fig. 4. As anticipated, there is at every frequency

[5] S. S. Stevens and H. Davis, *Hearing* (John Wiley, 1938), p. 262.

an advance of phase. The effect is more distinct at 1000 and 2000 cycles. This again, is in qualitative agreement with the theoretical curve in Fig. 3, which shows maximal shift at resonance frequency.

SUMMARY

1. Interference with the sound-conductive mechanism causes a change in phase of the electrical cochlear response.

2. This effect does not consist in a sudden reversal of phase, but in a gradual shift. The former conception led to difficulties in understanding the course of deafness in otosclerosis, as pointed out by Pohlman. Considering the actual phase shift, as seen in the experimental oscillograms, we find that this paradox does not arise.

3. Injecting oil into the middle ear causes a phase shift which is qualitatively the same as the one theoretically expected in a simple vibrating system when friction is increased.

4. If the malleus is put under constant pressure, a phase shift results which is similar to the one caused in a simple vibrating system by increased stiffness.

APPENDIX

Let a periodical force $F=F_0e^{j\omega t}$ of a frequency $\omega/2\pi$ act on a simple vibrating system. The differential equation of vibration is

$$md^2x/dt^2+rdx/dt+sx=F, \tag{1}$$

where m = mass, r = friction, s = stiffness, x = displacement, and $j=\sqrt{-1}$. The steady state solution of the equation is

$$x=x_0e^{j\omega t}. \tag{2}$$

Substitution of (2) into (1) yields $F/x=(s-m\omega^2)+j\omega r$. Let two different sets of constants be denoted by (m_1, r_1, s_1) and (m_2, r_2, s_2), respectively. The ratio of displacements is then, the acting force remaining unchanged,

$$x_2/x_1=[(s_1-m_1\omega^2)+j\omega r_1]/[(s_2-m_2\omega^2)+j\omega r_2].$$

From this equation, it follows that the corresponding phase shift (δ) is

$$\delta=\arctan\frac{\omega r_1}{s_1-m_1\omega^2}-\arctan\frac{\omega r_2}{s_2-m_2\omega^2}.$$

Curve 1, Fig. 3, was computed by assuming

$$m_2=m_1=1, \quad r_2=2r_1=2, \quad s_2=s_1=1.$$

Curve 2, Fig. 3, was obtained by choosing

$$m_2=m_1=1, \quad r_2=r_1=1, \quad s_2=2s_1=2.$$

These values are, of course, purely arbitrary and have no bearing on actual magnitudes. Only the qualitative change is of importance for the problem. It may be noted that the same values would have been obtained if, instead of ratios of displacement (x), the change of velocity (dx/dt) had been computed.

Erratum: The Correlation Between Elastic Deformation and Vertical Forces in Lateral Recording

(J. Acous. Soc. Am. **13**, 284 (1942))

S. J. BEGUN AND T. E. LYNCH
The Brush Development Company, Cleveland, Ohio

March 2, 1942

UNDER formula (3)

$$P=F\sin\beta/2 \text{ should read } P=\frac{F/2}{\sin\beta/2}.$$

Formula (4) should read

$$d=\left(\frac{(4.27F)^2}{E^2\sin^5\beta/2}\right)^{\frac{1}{3}}.$$

Formula (5b) should read

$$d_M=\left(\frac{12.4F}{E}\right)^{\frac{1}{3}}.$$

These changes result in a slight reduction in the permissible biasing forces shown in Fig. 5. The error also detracts somewhat from the accuracy of the d_M column of the nomograph.

Acoustical Society News

Future Meetings

THE next meeting of the Acoustical Society will be held in Ann Arbor soon after this issue is mailed; namely, Friday and Saturday, May 15 and 16. Hotel accommodations may be reserved by writing the Michigan Union, Ann Arbor.

National Science Fund

THE National Academy of Sciences has recently announced the establishment of the National Science Fund, a philanthropic organization established for the purpose of administering funds which may be given for the advancement of science and providing advice to any prospective donor interested in science. All scientists should be familiar with this organization in order that they may suggest its service to any individual or group contemplating a gift. This service is explained in detail in a booklet entitled "Philanthropy in Science," which may be obtained from The National Science Fund, 515 Madison Avenue, New York City.

Civil Service Examinations for Scientists Reannounced

IN an effort to meet the increasing needs of the defense program for scientifically trained men and women, the Federal Civil Service Commission has reannounced, with modified requirements, three of its examinations for scientists. The reannounced examinations are those for Physicist, Explosives Chemist, and Chemical Engineer positions, with salaries in each field ranging from $2600 to $5600 a year. For all, appropriate college study and experience are required.

In the field of physics, there is great demand for physicists well qualified in stress analysis, ballistics, elasticity, vibration studies, vacuum-tube circuits, and short radio waves. Provision is made in the new announcement for accepting applications for the assistant grade positions ($2600 a year) from applicants who wish to qualify on college teaching unaccompanied by research.

In chemical engineering the Commission has adequate employment lists in some branches. However, there is a shortage of qualified people in plant layout, equipment design, market analysis, chemical economics, heavy chemicals, plastics, rubber, agricultural by-products, and strategic minerals. Applicants may now substitute college teaching in chemical engineering or chemistry for part of the prescribed experience.

In the new Physicist and Chemical Engineer examinations, the recency requirements relative to experience have been modified. Although preference in certification will be given to those eligibles who acquired at least 1 year of their required education or experience within the 10 years immediately preceding the filing of their applications, those whose qualifying education or experience was gained previous to that 10-year period may be certified and appointed.

Over 100 Explosives Chemists are needed. In this examination the term "explosives chemistry" is interpreted to mean "research, developmental or production work on explosives, or materials which require for their preparation and handling, methods, techniques, and precautionary measures similar to those used for explosives." There is no longer a "recency" clause in the announcement, and an applicant's experience may therefore have been gained at any time.

For all of these examinations the age limit has been raised to 60 years, for regular probational appointment. Provision is also made for the waiver of age and physical requirements for temporary positions connected with the defense program. The announcements and application forms may be obtained at any first- or second-class post office or from the Civil Service Commission in Washington, D. C. Applications may be filed until further notice but qualified persons are urged to apply at once.

Summer Acoustics Course at Brown University

BROWN University will be one of four universities in the United States where special advanced work in acoustics will be carried out this summer to train men needed for research and experimentation in Navy laboratories.

The program at Brown is designed to provide fundamental background knowledge and experience on problems related to submarine detection, acoustic mines, sound insulation and the field of sound transmission. A variety of topics bearing on advanced problems will be weighed.

As a part of the Engineering, Science and Management Defense Training program of the United States Office of Education, the lectures and laboratory work for the new summer course are to be offered free to qualified students with special ability in physics and mathematics.

Professor R. Bruce Lindsay, Chairman of the Department of Physics, will be in charge of the program, assisted by Louis W. Labaw, a graduate student who is a candidate for his Ph.D. degree in acoustics. Professor Lindsay is an author of a recognized text on acoustics, written jointly with Professor George W. Stewart of the University of Iowa. For the past fifteen years Professor Lindsay's research has been directed towards special acoustical problems.

Beginning on June 15, the lectures and discussion periods will be held five days weekly for eleven weeks. Two three-hour laboratory periods weekly are also scheduled. Concentrated and comprehensive, the work will cover the equivalent of a year's study.

Brown was chosen as one of the centers for study in acoustics because of the high quality of the university's research in the transmission of high frequency sound in air and in water, and for Brown's extensive laboratory equipment for acoustical investigations.

Other colleges and universities approved by the Navy Department as centers for similar studies are the University of California at Los Angeles, the University of Iowa, and the Case School of Applied Science in Cleveland.

New Members

Douglas Edwin Agren
4832 University
Detroit, Michigan
Mechanical Engineer
Industrial Wire Cloth Products Corporation
Wayne, Michigan

Maurice Evan Bell
Physicist
Cruft Laboratory, Harvard University
Cambridge, Massachusetts

Bruce Hadley Billings
41 Bowdoin Street
Cambridge, Massachusetts
Research Physicist
Polaroid Corporation
Cambridge, Massachusetts

Clarence Bader Brouilette
10 Clinton Street
Hartford, Connecticut
Sales Representative
C. A. Bader Company
10 Clinton Street
Hartford Conn.

Charles Arthur Cady
General Radio Company
30 State Street
Cambridge, Massachusetts

Richard W. Carlisle
Box 356, Elmsford
New York
Electro-Acoustic Research Engineer
Sonotone Corporation
Elmsford, New York

Trevor H. Clark
67 Broad Street
New York, New York
Engineering Physicist
International Telephone and Radio Corporation
67 Broad Street New York

James Keane Connolly
Holy Cross College
Worcester, Massachusetts

Thomas Henry Coulter
135 South LaSalle Street
Chicago, Illinois

Hayden Wiley Evans
Room 1002A, 180 Varick Street
Technical Staff
Bell Telephone Laboratories
New York, New York

Albert Edward Gessler
Interchemical Corporation Research Laboratories
432 West 45th Street
New York, New York
Director of Research

Robert L. Hanson (Reinstated)
Bell Telephone Laboratories
463 West Street
New York, New York

Howard Cecil Hardy
Physics Department, University of New Hampshire
Durham, New Hampshire
Instructor of Physics

Robert Gray Hughes
P.O. Box 8989
21 Esplanade Mancions
Calcutta, India
Director, Armco India Limited
Calcutta, India

Robert Clark Jones
Room 857
Bell Telephone Laboratories
463 West Street
New York, New York

Clarence Joseph LeBel
370 Riverside Drive
New York, New York

Robert Walton Leonard
1867 Greenfield Avenue
Los Angeles, California
Instructor in Physics, University of California at Los Angeles

Charles Warner McWilliams
7 Irving Terrace
Cambridge, Massachusetts
Research Assistant, Cruft Laboratory
Harvard University
Cambridge, Massachusetts

Howard George Meinke
4 Irving Place
New York, New York
Division Engineer, Consolidated Edison Company of New York, Inc.

Elbert Raymond Moses, Jr.
4499 Rosemont Place
Columbus, Ohio
Assistant Professor of Speech
The Ohio State University
Columbus, Ohio

Ernest H. Peabody
580 Fifth Avenue
New York, New York
Engineer

Robert Irving Sarbacher
5555 Sheridan Road
Chicago, Illinois
Professor of Electrical Engineering
Illinois Institute of Technology
Chicago, Illinois

Daniel Silverman
Box 591
Tulsa, Oklahoma

Donald Orr Sproule
Henry Hughes and Company, Ltd.
Husun Works
New North Road
Barkingside, Ilford, Essex
England

Paul Schuleke Veneklasen
1441 Westwood Boulevard
Los Angeles, California
Graduate Student, Physics Department
University of California at Los Angeles
Los Angeles, California

Don Holtgren Young
95–25 149th Street
Jamaica, New York

Transferred to Fellowship: Lonsdale Green, Jr.
Resigned: Bruce R. Herr, Wilmer H. Tucker, Members
George T. Stanton, Fellow

Fellows	168
Members	661
Total membership	829

Current Publications on Acoustics

Book Reviews

Dictionary of Radio and Television Terms. RALPH STRANGER. Pp. 252. Chemical Publishing Company, Brooklyn, New York. Price $2.50.

This dictionary is designed to provide quick reference for all students of radio and television who may in reading technical books come across terms which are unfamiliar to them. The book contains in addition to valuable definitions, over a hundred figures, illustrations and diagrams. The appendix contains a useful list of conventional symbols and various types of tables. The terms defined are those used principally in electricity, radio, and television, only a few pertaining to acoustics.

F. A. FIRESTONE
University of Michigan

Automatic Record Changers and Recorders. JOHN F. RIDER. Pp. 744. John F. Rider Publisher, Inc., New York, New York. Price $6.00.

The first 60 pages of this service man's encyclopedia is devoted to a general description of the automatic record changer mechanism, turn-table drives, cutting heads for recorders, recording needles, etc. The remainder of the book covers exhaustively the detailed structure and operation of the many commercial recorders, reproducers, and automatic record changers. The book is "dedicated to the radio service man who, through no fault of his own, now is surrounded with pawls and cams and gears."

F. A. FIRESTONE
University of Michigan

References to Contemporary Papers on Acoustics

MOST of the titles of papers appearing in other languages than English have been translated. Abstracts in English of many foreign papers have appeared or soon will appear in Science Abstracts, Section A. Where references are made to Science Abstracts, the reference is to the volume number and abstract number. The abbreviations of the names of journals are those used in Science Abstracts and can be found in any annual index to those abstracts.

The numbers appearing at the head of each entry are the numbers which identify the subject headings in the Cumulative Index of this journal issued in November, 1939. This same Classification of Subjects can be found in the index to Volume 13, this issue.

Compiled with the generous assistance of Samuel Sass, Physics Librarian, University of Michigan.

2. ARCHITECTURAL ACOUSTICS

2.2 **Factors Affecting Sound Quality in Theaters.** A. GOODMAN. J. Soc. Mot. Pic. Eng. **37**, 510–515 (Nov. 1941).

2.2 **Acoustics of Cinema Auditoria.** C. A. MASON AND J. MOIR. I.E.E., J. **88**, Part 3, No. 3, 175–186 (Sept. 1941). Abs., Wireless Engineer **18**, 3071 (1941).

2.2 **On the Audibility of Echo and Its Influence on the Intelligibility of Speech.** A. RABINOVICH. J. Techn. Physics **10**, 605–616 (1940). (In Russian.)

2.3 **Acoustics of Cinema Auditoria.** C. A. MASON AND J. MOIR. I.E.E., J. **88**, Part 3, 175–186; disc. 186–190 (Sept. 1941). Sci. Abs. **A44**, 2381 (1941).

2.4 **On Sound Absorption by Resonators.** V. L. JORDAN. Akustische Zeits. **5**, 77–87 (March, 1940). Sci. Abs. **A44**, 2700 (1941).

2.4 **Measurement of Coefficient of Reflection and Phase for Sound Waves.** C. KANTA. Nat. Inst. Sci., India, Proc. **6**, 671–693 (1940). Sci. Abs. **A44**, 1454 (1941).

2.4 **The Absorption of Sound by Means of a Three-Layer Resonance System.** V. NESTEROV. J. Techn. Physics **10**, 617–626 (1940). (In Russian.)

2.7 **Reverberation Time and Attenuation Constant with Grazing Incidence.** L. CREMER. Akustische Zeits. **5**, 57–76 (March, 1940). Sci. Abs. **A44**, 2701 (1941).

2.9 **Fiberglas Quiets Roar in Test Cells.** Aviation **41**, 104–105 (Jan. 1942).

2.9 **Owens-Corning Fiberglas Corporation; Sound Stacks for Absorption of Noises Set Up by Airplane Engines and Propellers While They Are being Tested.** J. Aeronaut. Soc. Aeronaut. R. Sec. **9**, 47 (Dec. 1941).

2.10 **Investigations on Sound Conduction in Water-Filled Pipes.** E. GANITTA. Akustische Zeits. **5**, 87–102 (March, 1940). Sci. Abs. **A44**, 2696 (1941).

4. EAR AND HEARING

4.1 **A Note on the Nature of Tone.** A. V. BERGER. J. Aesthet. **1**, Nos. 2–3, 86–91 (1941).

4.1 **Function of the Cerebral Cortex in Audition.** W. A. HUNTER. J. Comp. Psychol. **32**, 117–138 (Aug. 1941).

4.1 **The Effect of Sound on the Limits of Visual Color Fields.** P. A. JAKOVLEV. Vestn. Oftal. **17**, 459 (1940).

4.1 **Experimental Observations on the Question of Auditory Fatigue.** H. G. KOBRAK, J. R. LINDSAY, AND H. B. PERLMAN. Laryngoscope, St. Louis **51**, 798–809 (1941).

4.1 **Total Interference in Relation to Cochlear Injury.** E. G. WEVER AND M. LAWRENCE. J. Exp. Psychol. **29**, 283–95 (Oct. 1941).

4.2 **The Clarification of Certain Phases of the Physiology of Hearing.** H. DAVIS. Laryngoscope, St. Louis **50**, 747–755 (1940).

4.2 **The Nature of Cochlear Activity After Death.** E. G. WEVER, C. W. BRAY, AND M. LAWRENCE. Psychol. Bull. **38**, 548–549 (1941).

4.3 **The Significance of Audible Onset as a Cue for Sound Localization.** D. P. BODER. Psychol. Bull. **38**, 547 (1941).

4.3 **The Loudness Gain by Binaural Heating, and Its Significance.** K. BRAUN. T.F.T. **29**, 343–345 (Dec. 1940); Wireless Engineer **18**, 3368A (1941).

4.3 **Behaviour of Time-Difference and Phase-Difference in the Binaural Effect.** Y. KIKUTI AND T. YOSIDA. Jap. J. Med. Sci. Biophys. **7**, 71–77 (1940).

4.4 **An Analysis of Hearing Aid Requirements and How They are Met.** Booklet published by The Vacolite Company, Dallas, Texas.

4.4 **Impaired Hearing in School Children.** S. R. GUILD ET AL. Laryngoscope, St. Louis **50**, 731–746 (1940).

4.4 **New Tests and Clinical Experiments on Hearing.** F. W. KOBRAK. J. Laryng. **55**, 405–423 (1940).

4.5 **Ear Plugs Protect Industrial Workers from Noise.** Scient. Am. **166**, 75 (Feb. 1942).

4.5 **Ideals and Standards for Audiometers and Hearing Aids.** N. A. WATSON. Volta Rev. **43**, 609–610 (Oct. 1941).

4.6 **The Loudness Gain by Binaural Hearing, and Its Significance.** T.F.T. **29**, 343–345 (Dec. 1940); Wireless Engineer **18**, 3368A (1941).

4.9 **A Study of Absolute Pitch.** C. H. WEDELL. Psychol. Bull. **38**, 547–548A (1941).

4.10 **Designation of Combination Tones.** E. G. WEVER. Psychol. Rev. **48**, 93–104 (March, 1941).

4.11 **Hearing and Equilibrium. A New Place Theory of Hearing.** H. MACNAUGHTON JONES. Baltimore: Williams and Wilkins (1940).

4.12 **A Study of Auditory "Brightness."** R. W. BURNHAM. Psychol. Bull. **38**, 546–547A (1941).

4.12 **The Quality of a Musical Tone.** C. E. SEASHORE. Psychol. Bull. **38**, 548A (1941).

5. APPLIED ACOUSTICS, INSTRUMENTS AND APPARATUS

5.1 **Sensitive Flames. III.** H. ZICKENDRAHT. Helv. Phys. Acta **14**, 195–214 (1941). Sci. Abs. **A44**, 2693 (1941).

5.3 **Measurement of Acoustical Impedances.** CHANDRA KANTA. Indian Journ. Phys. **15**, 161–171 (June, 1941).

5.4 **Sound Analysis with Mechanical Band Filter and High Carrier Frequency.** G. BUCHMANN. Akustische Zeits. **5**, 7–10 (Jan. 1940). Sci. Abs. **A44**, 2699 (1941).

5.7 **Recording of Small Variations in Pitch.** M. GRÜTZMACHER AND W. LOTTERMOSER. Akustische Zeits. **5**, 1–6 (Jan. 1940). Sci. Abs. **A44**, 2703 (1941).

5.8 **Baffling the Loudspeaker.** R. M. GILBERT. Radio No. 264, 32–35 (Dec. 1941).

5.8 **Cone Speaker Projectors.** Electronics **15**, No. 1, 103 (Jan. 1942).

5.8 **Recent Research and Its Effect Upon Loudspeaker Design.** E. and Television and S-W.W. **14**, No. 158, 174–176 (April, 1941).

5.8 **Speaker Volume Control.** Electronics **14**, No. 12, 92 (Dec. 1941). (One paragraph.)

5.8 **Two-Way Baffle.** (One paragraph.) Electronics **14**, No. 12, 95 (Dec. 1941).

5.9 **Microphone Mounting (in Motion Picture Work).** Electronics **14**, No. 12, 95 (Dec. 1941).

5.9 **Super-Cardioid Directional Microphone.** B. B. BAUER. Electronics **15**, No. 1, 31–33, 91–93 (Jan. 1942).

5.9 **Thermal Damping in Air Gaps of Microphones.** H. PFRIEM. Akustische Zeits. **5**, 103–111 (March, 1940). Sci. Abs. **B44**, 1786 (1941).

5.9 **Microphone Combination Insensitive to Noise and Acoustic Retroaction.** S. SAWADE. Hochfrequenztechn. u. Elektroakustik **57**, No. 6, 165 (June, 1941).

5.10 **Aeroplane "Spotting" by Electro-Acoustical Methods.** E. and Television and S-W.W. **14**, 153–154 (April 1941).

5.10 **Detecting Trapped Persons (After Air Raids with Sound-Amplifying Apparatus).** El. Rev. **129**, 363 (Oct. 10, 1941).

5.10 **Sensitive Microphones Spot Hidden Guns.** H. POWELL. Pop Sci. **140**, 71–72 (Jan. 1942).

5.15 **Aeronautic Decibels; A Handy Noise Meter for Aircraft Use.** Sci. Am. **165**, 351 (Dec. 1941).

5.15 **A New Reference-Attenuation Meter with Objective Excitation and Indication.** K. BRAUN. T.F.T. **29**, 223–227 (Aug. 1940); Wireless Engineer **18**, 3371A (1941).

5.15 **Averaging Decibel Measurements.** M. RETTINGER. Communications **21**, No. 7, 11–12 (July, 1941).

5.15 **An A-C-Operated Power Supply for the Sound-Level Meter.** H. H. SCOTT. Gen. Rad. Experimenter **16**, No. 8, 1–3 (Jan. 1942).

5.16 **A Variable-Speed Turntable Unit.** E. and Television and S-W.W. **14**, 110 (March, 1941).

5.16 **Sapphire Needle (curved to meet the record straight on, without drag).** One paragraph. Electronics **14**, No. 12, 95 (Dec. 1941).

5.16 **Stereophonic Sound Film System.** J. of Applied Physics **13**, 32–33 (Jan. 1942).

5.16 **Analysis of Sound-Film Drives.** W. J. ALBERSHEIM AND D. MACKENZIE. J. Soc. Mot. Pic. Eng. **37**, 452–479 (Nov. 1941).

5.16 **Recording Blanks.** D. W. ALDOUS. Wireless World **47**, 269–270 (Oct. 1941).

5.16 **Standards for Electrical Transcriptions.** H. A. CHINN. Communications **21**, No. 9, 10–11, 33 (Sept. 1941).

5.16 **A High-Fidelity Phonograph Amplifier.** R. L. DAWLEY. Radio, No. 266, 7–10, 53 (Feb. 1942).

5.16 **The Technique of the Commercial Gramophone-Disk Recording Process.** W. A. GÜNTHER. Assoc. Suisse Élect., Bull. **32**, 291–296 (July, 1941). (In German). Sci. Abs. **A44**, 2382 (1941).

5.16 **A New High-Quality Soundhead.** R. H. HEACOCK. RCA Rev. **5**, 283–292 (Jan. 1941); Wireless Engineer **18**, 3075A (1941).

5.16 **High Quality Lateral Disc Recording.** H. P. MEISINGER. Radio No. 265, 41–44 (Jan. 1942).

5.16 **Re-Coating Recording Blanks.** W. H. PIERCE. Wireless World **47**, 242–243 (Sept. 1941).

5.16 **Solving Acoustic and Noise Problems Encountered in Recording for Motion Pictures.** W. L. THAYER. J. Soc. Mot. Pic. Eng. **37**, 525–534 (Nov. 1941).

5.16 **Spatial Reproduction in Broadcasting and Sound Films.** M. VYSOCKIJ AND V. KONOPLEV. Zh. tekh. Fiz. **8**, 399–407 (1938).

5.17 **Quiet, Please.** (Paragraph on sound-protected telephone booth.) Frank. Inst. J. **232**, 605 (Dec. 1941).

5.51 **Method of Microphone Pick-up for Moving and/or Extensive Sound Sources.** H. BENECKE. Hochfrequenztechn. u. Elektroakustik **57**, No. 6, 164 (June, 1941).

6. Musical Instruments and Music

6.1 **Polytone and the Potentialities of a Purer Intonation.** Mus. Quarterly **27**, 371–83 (July, 1941).

6.1 **The Measurement of the Frequency of the Tuning Note (La_3) during a Musical Performance.** A. BARONE. Ricerca Scientifica **11**, 961–977 (Dec. 1940); Wireless Engineer **18**, 3076A (1941).

6.1 **The Comma in Music.** A. F. DUFTON. Phil. Mag. **32**, 259–621 (Sept. 1941).

6.1 **Recording of Small Variations in Pitch.** M. GRUTZMACHER AND W. LOTTERMOSER. Akustische Zeits. **5**, 1–6 (Jan. 1940). Sci. Abs. **A44**, 2703 (1941).

6.1 **Musical Acoustics.** E. G. RICHARDSON. Reports on Progress in Physics **7**, 27–35 (1940).

6.4 **Flower Pots Used in Symphony to Provide "New and Unusual Tones."** Radio, No. 266, 25 (Feb. 1942).

6.5 **Negative Characteristic of the Pipe Reed.** ZAHRADNICEK AND NESPOR. Phys. Zeits. **41**, 419–421 (Sept. 1940).

6.7 **Tests at the National Institute of Electro-acoustics to Arrive at an Objective Estimate of the Acoustical Quality of Some Violins.** G. PASQUALINI. Ricerca Scientifica **11**, 622–639 (Sept. 1940).

6.8 **Investigations on Flutes à bec.** A. VON LÜPKE. Akustische Zeits. **5**, 39–46 (Jan. 1940); Sci. Abs. **A44**, 2692 (1941).

6.9 **Tone Synthesis with the Toothed-Wheel Generator.** Phys. Zeits. **42**, 111–116 (April, 1941); Sci. Abs. **A44**, 2142 (1941).

7. Noise

7.4 **Less Noise in More Places.** Commonweal **35**, 61 (Nov. 7, 1941).

7.4 **Quiet, Please.** (Paragraph on sound-protected telephone booth.) Frank. Inst. J. **232**, 605 (Dec. 1941).

7.4 **Ever-rising Sea of Sounds.** W. MIKELSON. Sci. Digest **10**, 45–7 (August, 1941).

7.4 **Sound and the Fury; E. H. Peabody and the League for Less Noise.** New Yorker **17**, 28–30 (Nov. 22, 1941).

7.7 **Fiberglas Quiets Roar in Test Cells.** Aviation **41**, 104–5 (Jan. 1942).

7.7 **Owens-Corning Fiberglas Corporation; Sound Stacks for Absorption of Noises Set Up by Airplane Engines and Propellers while They are Being Tested.** J. Aeronaut. Soc. Aeronaut. R. Sec. **9**, 47 (Dec. 1941).

9. Speech and Singing

9.6 **Sonovox, New Radio Prop.** Sci. Digest **10**, 93 (Oct. 1941).

9.6 **The "Acoustic Envelope": New Development to Aid Voice Production.** H. BURRIS-MEYER. Wireless World **47**, 233 (Sept. 1941); Wireless Engineer **18**, 3390A (1941).

10. Supersonic (Ultrasonics)

10.3 **A Quartz Plate with Coupled Liquid Column as a Variable Resonator.** F. E. FOX AND G. D. ROCK. I.R.E., Proc. **30**, 29–33 (Jan. 1942).

10.3 **The Electrical Breakdown of Rochelle Salt.** B. V. GORELIK. J. Techn. Physics **10**, 369–375 (1940); (In Russian). Wireless Engineer **18**, 3375A (1941).

10.3 **Preparation of Quartz Ultrasonic Oscillators.** R. R. BAJPAI AND V. I. VAIDHIANATHAN. Indian Acad. Sci., Proc. **A13**, 504–509 (June, 1941); Sci. Abs. **A44**, 2697 (1941).

10.4 **Sound Absorption, Specific Heat, and Relaxation Time of Electron Spin in Nitrogen.** Ann. d. Physik [5] **39**, 261–272 (April 9, 1941).

10.4 **Plane Waves in Ideal Gases with Friction and Heat Conduction.** K. BECHERT. Ann. d. Physik **40**, 207–248 (Aug. 30, 1941).

10.4 **Sound Absorption, Specific Heat and Period of Adjustment of the Electron Spin in NO.** H. O. KNESER. Ann. d. Physik. Lpz. **39**, 261–272 (April, 1941); Sci. Abs. **A44**, 2385 (1941).

10.4 **Dispersion of Sound Waves, Considering the Effects of Heat Conduction and Viscosity.** Z. SAKADI. Phys. Math. Soc., Japan, Proc. **23**, 208–213 (March, 1941); Sci. Abs. **A44**, 2376 (1941).

10.5 **Ultrasonic Velocities in Solutions.** L. SIBAIYA AND R. L. NARASIMHAIYA. J. Mysore Univ. **B1, 15**, 133–140 (1941); Sci. Abs. **A44**, 2380 (1941).

10.6 **Ultrasonics (with particular attention to metallurgical applications).** Metallurgist (Supp. to Engineer) (Aug. 29, 1941), p. 25; Wireless Engineer **18**, 3079A (1941).

10.6 **Supersonic Dispersion and Speed of Fracture.** A. SMEKAL. Phys. Zeits. **41**, 475–480 (Oct. 15, 1940); Sci. Abs. **A44**, 1962 (1941).

10.9 **Short Wave Sound Generator Used to Kill Bacteria.** (One paragraph.) Radio, No. 266, 27 (Feb. 1942).

10.9 **Observations on the Effects of Sound and Supersonic Waves on the Protein of the Tobacco-Mosaic Virus.** G. A. KAUSCHE ET AL. Naturwiss. **29**, 573–574 (Sept. 19, 1941).

11. WAVES AND VIBRATIONS

11.3 **Propagation of Sound through the Atmosphere; Bearing on Audibility of Aircraft and on Exploration of Altitudes.** B. HAURWITZ. Aeronaut. Sciences, J. **9**, 35–43 (Dec. 1941).

11.3 **Sound Propagation in the Open Air, and Its Dependence on Meteorological Conditions.** H. SIEG. E.N.T. **17**, 193–308 (Sept. 1940); Wireless Engineer **18**, 3379A (1941).

11.3 **The Velocity of Sound in Methyl Methacrylate Polymer.** L. R. WEBER AND F. P. GOEDER. Phys. Rev. **61**, 94–95 (Jan. 1 and 15, 1942).

11.5 **Method of Generating Extremely Strong Stationary Sound Waves in Air.** H. OBERAT. Akustische Zeits. **5**, 27–38 (Jan. 1940); Sci. Abs. **A44**, 2694 (1941).

11.5 **On the Equivalent Diagram of the Spherical Detonation.** L. CREMER. Akustische Zeits. **5**, 46–50 (Jan. 1940); Sci. Abs. **A44**, 2704 (1941).

11.6 **The Propagation of Pressure Fluctuations of Large Amplitude in Air Columns.** L. J. KASTNER. Phil. Mag. **32**, 206–224 (Sept. 1941).

11.6 **Investigations on Sound Conduction in Water-Filled Pipes.** E. GANITTA. Akustische Zeits. **5**, 87–102 (March, 1940); Sci. Abs. **A44**, 2696 (1941).

11.6 **Method of Generating Extremely Strong Stationary Sound Waves in Air.** H. OBERST. Akustische Zeits. **5**, 27–38 (Jan. 1940); Sci. Abs. **A44**, 2694 (1941).

11.7 **On the Differential Equations of Wave Propagation in Gases.** K. BECHERT. Ann. d. Physik **29**, 357–372 (May 4, 1941); Wireless Engineer **18**, 3078A (1941).

11.7 **The Admittance Method for Obtaining the Natural Frequencies of Systems.** W. J. DUNCAN. Phil. Mag. **32**, 401–409 (Nov. 1941).

11.7 **Modulus of Elasticity of Dinnerware Bodies by a Sonic-Vibration Method.** S. V. FORGUE AND G. A. LOOMIS. Am. Cer. Soc., Bull. **20**, 425–30 (Dec. 1941).

11.7 **Sound Radiation Pressure in Liquids and Gases in Connection with the Equation of State.** G. HERTZ. Phys. Zeits. **41**, 546–549 (Dec. 15, 1940); Sci. Abs. **A44**, 2138 (1941).

11.7 **Note on the Doppler Effect.** C. S. MCILWRAITH. Rev. Sci. Instruments **12**, 612 (Dec. 1941).

11.7 **A Measuring Equipment with Direct Indication for the Determination of the "Klirr" Factor and Individual Harmonics.** H. RUPP. E.N.T. **17**, 247–261 (Nov. 1940); Wireless Engineer **18**, 3400A (1941).

11.7 **On Acoustically Effective Vortex Motion in Gaseous Jets.** P. SAVIC. Phil. Mag. **32**, 245–252 (Sept. 1941).

11.7 **Gravest Mode of Some Vibrating Systems.** B. R. SETH. Indian Acad. Sci., Proc. **A13**, 390–394 (May, 1941); Sci. Abs. **A44**, 2131 (1941).

11.7 **Transverse Vibrations of Triangular Membranes.** B. R. SETH. Indian Acad. Sci., Proc. **A12**, 487–490 (Nov. 1940); Sci. Abs. **A44**, 2691 (1941).

11.7 **Akustische Resonatoren und Ihre Kopplung.** H. ZICKENDRAHT. Helv. Phys. Acta **14**, 309–311 (Oct. 1941).

11.7 **Laboratory Experiments with Acoustic Resonators.** PAUL L. COPELAND. Am. J. Phys. **9**, 375–378 (Dec. 1941).

Review of Acoustical Patents

HERBERT A. ERF
The H. A. Erf Acoustical Company, Cleveland, Ohio

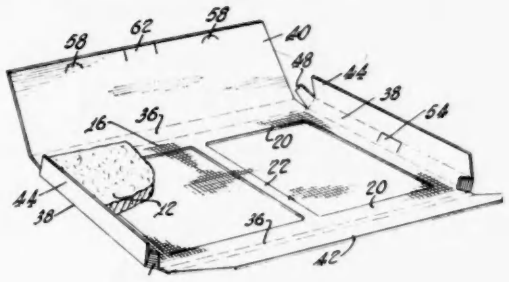
Printed copies of patents are furnished by the Patent Office at a cost of 10¢ each. Address all communications to: The Commissioner of Patents, Washington, D. C. Remittances should be made by postal money order, certified check or cash. Do not send stamps.

The decimal numbers appearing before each title are the numbers which identify the subject headings in the Cumulative Index of this journal issued in November, 1939.

2,253,953

2.2 ACOUSTICAL ASSEMBLY

James Y. Dunbar, assignor to Johns-Manville Corporation.
August 26, 1941, U.S.P.O. Cl. 154–44, 5 Claims.



A sound absorbing pad and cover for same.

2,265,770

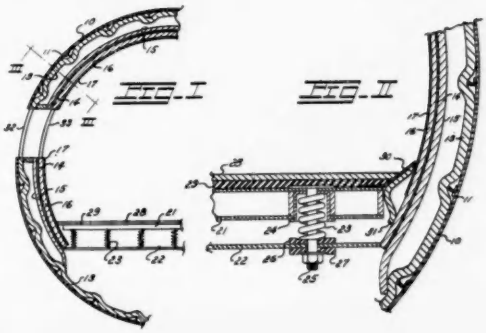
2.4 COMPOSITION OF MATTER

Richard A. Crawford, assignor to The B. F. Goodrich Company.
December 9, 1941, U.S.P.O. Cl. 260–722, 2 Claims.

2,263,919

2.9 SOUND AND VIBRATION INSULATION FOR AIRCRAFT CABINS

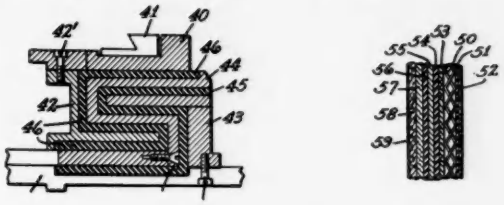
James B. Darragh, Jr., assignor to Lockheed Aircraf Corporation.
November 25, 1941, U.S.P.O. Cl. 20–4, 8 Claims.



2,252,285

2.9 SOUNDPROOF WALL STRUCTURE

William Eglinton and Harry Gail Cunningham, assignors to Radio Corporation of America.
August 12, 1941, U.S.P.O. Cl. 154–45.9, 4 Claims.

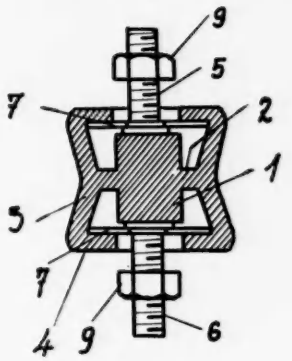


A soundproof wall construction for camera blimps.

2,268,306

2.11 VIBRATION DAMPENING DEVICE

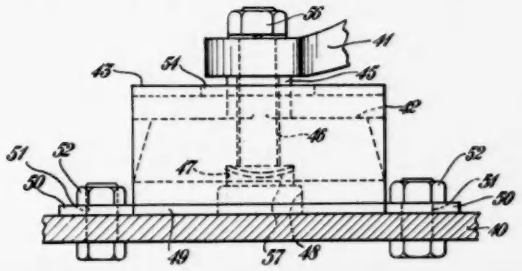
Tino Sarti, Milan, Italy.
December 30, 1941, U.S.P.O. Cl. 248–358, 2 Claims.



2,267,172

2.11 RESILIENT MOUNTING

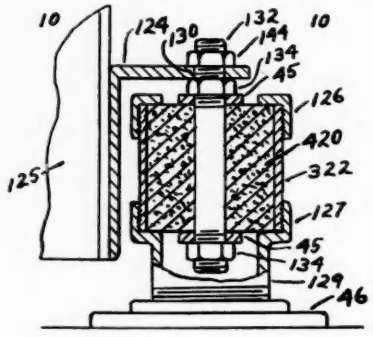
Curt Saurer, assignor to The Firestone Tire & Rubber Company.
December 23, 1941, U.S.P.O. Cl. 248–22, 2 Claims.



2,265,160

2.11 VIBRATION DAMPENING FITTING

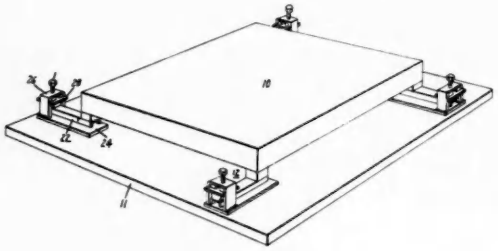
Clyde M. Hamblin.
December 9, 1941, U.S.P.O. Cl. 248–358, 2 Claims.



2,260,029

2.11 FLEXIBLE SUPPORTING ARRANGEMENT

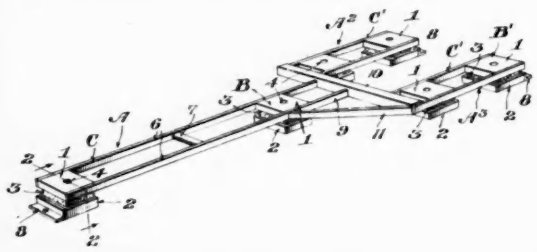
Edwin H. Hull, assignor to General Electric Company.
October 21, 1941, U.S.P.O. Cl. 248–22, 5 Claims.



2,259,214

2.11 VIBRATION ISOLATION BASE FOR MOTORIZED FANS AND THE LIKE

Siegfried Rosenzweig.
October 14, 1941, U.S.P.O. Cl. 248–22, 2 Claims.



2,253,025

2.11 VIBRATION DAMPING MEANS

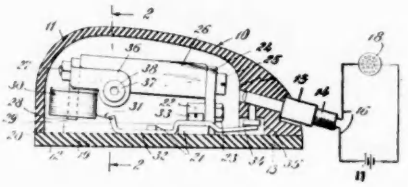
Alfred Hubert, Roy Fedden and Frank Nixon, Bristol, England, assignors to The Bristol Aeroplane Company Limited, Bristol, England.
August 19, 1941, U.S.P.O. Cl. 257–261, 7 Claims.

Vibration damping means for air-cooled internal-combustion engines.

2,258,638

4.5, 5.7 BONE CONDUCTION AUDIPHONE

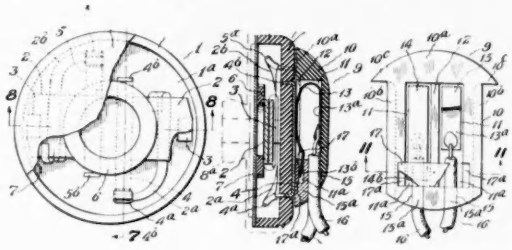
William A. Zarth, assignor to Dictograph Products Company, Inc.
October 14, 1941, U.S.P.O. Cl. 179–107, 8 Claims.



2,261,979

4.5, 5.7 ACOUSTIC DEVICE

Dante Domizi, assignor to The Brush Development Company.
November 11, 1941, U.S.P.O. Cl. 179–110, 10 Claims.

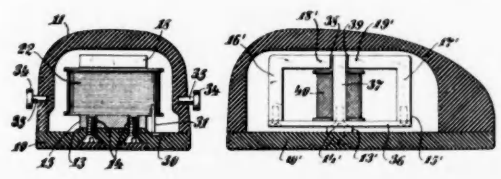


Connecting means for acoustic devices such as wearable hearing aids.

2,262,082

4.5 BONE CONDUCTION AUDIPHONE

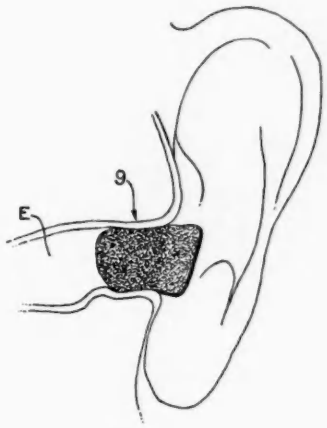
William A. Zarth, assignor to Dictograph Products Company, Inc.
November 11, 1941, U.S.P.O. Cl. 179–107, 8 Claims.



2,262,568

4.5 EAR PROTECTOR

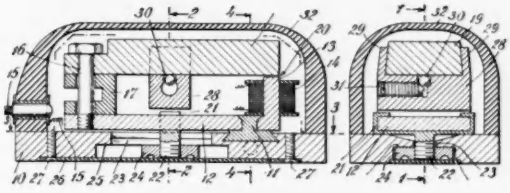
Kenneth L. Wade.
November 11, 1941, U.S.P.O. Cl. 128–152, 2 Claims.



2,264,684

4.5 BONE TELEPHONE RECEIVER

William T. Weidenman, Sr., assignor to Telephonics Corporation.
December 2, 1941, U.S.P.O. Cl. 179–107, 4 Claims.



2,266,669

4.5 HEARING AID DEVICE

Arthur M. Wengel, assignor to Ray-O-Vac Company.
December 16, 1941, U.S.P.O. Cl. 179–1, 2 Claims.

2,266,788

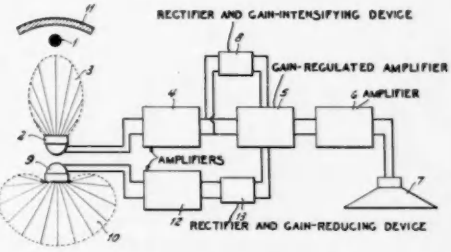
4.5 HEARING AID DEVICE

John B. Nelson and Willard C. Mason.
December 23, 1941, U.S.P.O. Cl. 179–107, 2 Claims.

2,263,233

5.1 ACOUSTIC APPARATUS

Werner Bürck, Berlin, Germany, assignor to Telefunken Gesellschaft für Drahtlose Telegraphic m. b. H., Berlin, Germany.
November 18, 1941, U.S.P.O. Cl. 179–1, 6 Claims.

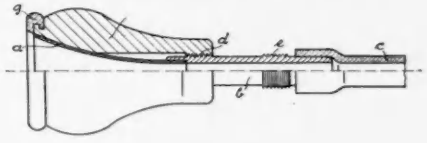


A system to prevent acoustic feedback of electroacoustic transducers in studio output circuit.

2,258,743

5.7 STETHOSCOPE

Albert Dax, Budapest, Hungary.
October 14, 1941, U.S.P.O. Cl. 181–24, 3 Claims.



2,260,210

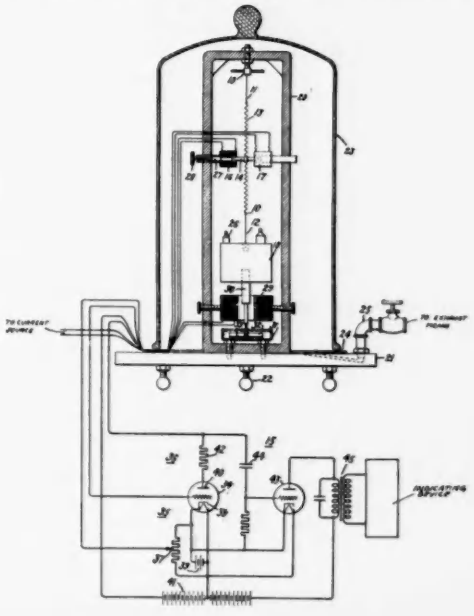
5.7 VISUAL TIP FOR VIBRATING INDICATORS

Roland B. Bourne, assignor to The Maxim Silencer Company.
October 21, 1941, U.S.P.O. Cl. 116–114, 3 Claims.

2,260,847

5.7 VIBRATORY FREQUENCY STANDARD

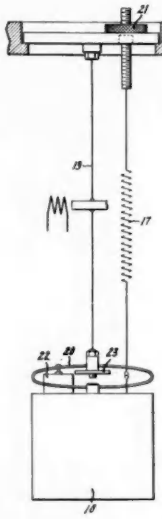
Henry E. Warren, assignor to Warren Telechron Company.
October 28, 1941, U.S.P.O. Cl. 171–123, 25 Claims.



2,260,848

5.7 VIBRATORY FREQUENCY STANDARD

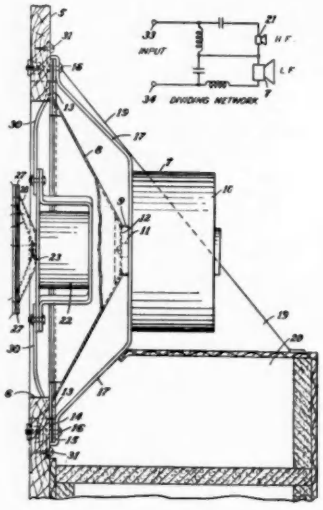
Henry E. Warren, assignor to Warren Telechron Company.
October 28, 1941, U.S.P.O. Cl. 171–123, 6 Claims.



2,259,907

5.8 SOUND REPRODUCING SYSTEM

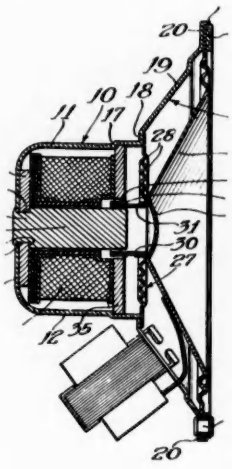
Benjamin Olney, assignor to The Stromberg-Carlson Telephone Mfg. Company.
October 21, 1941, U.S.P.O. Cl. 181–31, 4 Claims.



2,260,063

5.8 LOUDSPEAKER

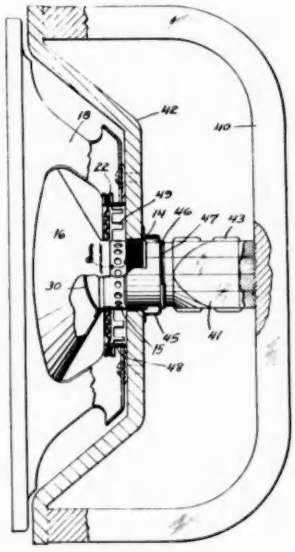
John McWilliams Stone and Carleton T. Weibler, assignors to Operadio Mfg. Co.
October 21, 1941, U.S.P.O. Cl. 179–115.5, 1 Claim.



2,261,110

5.8 LOUDSPEAKER

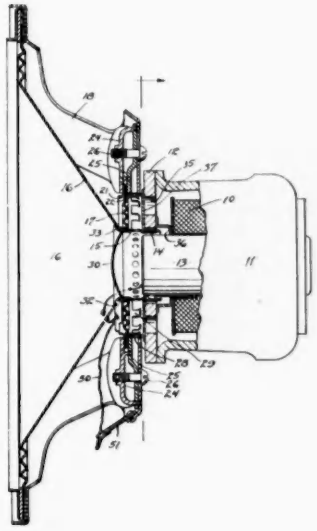
Bernard A. Engholm, assignor to The Rola Company.
November 4, 1941, U.S.P.O. Cl. 179–115.5, 9 Claims.



2,261,111

5.8 LOUDSPEAKER

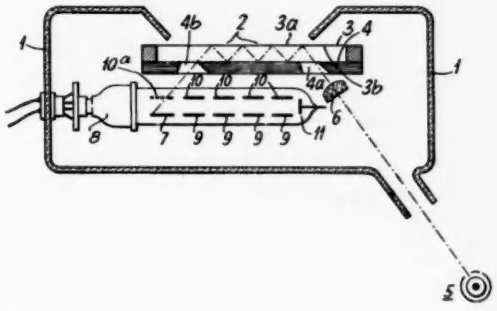
Bernard A. Engholm, assignor to The Rola Company.
November 4, 1941, U.S.P.O. Cl. 179–115.5, 7 Claims.



2,259,511

5.9 MICROPHONE

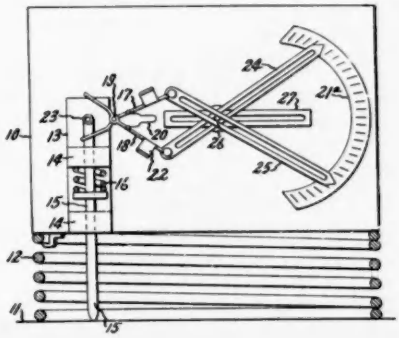
George Baldwin Banks, assignor to Radio Corporation of America.
October 21, 1941, U.S.P.O. Cl. 179–138, 3 Claims.



2,263,295

5.9 VIBRATION METER

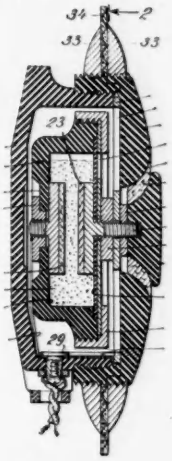
Charles D. Greentree, assignor to General Electric Company.
November 18, 1941, U.S.P.O. Cl. 73–51, 9 Claims.



2,260,727

5.9 CONTACT MICROPHONE

Sterling G. Sears and William T. Weidenman, Sr., assignors to Telephonics Corporation.
October 28, 1941, U.S.P.O. Cl. 179–123, 2 Claims.

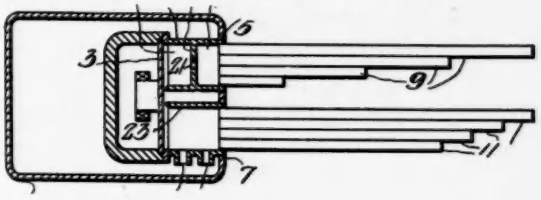


Contact type microphone whereby vibrations of the voice are reproduced directly from the throat or cheek.

2,262,146

5.9 SOUND TRANSLATING APPARATUS

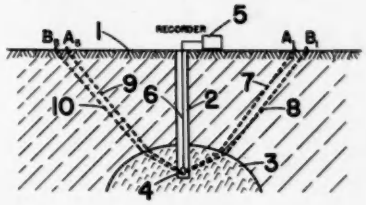
Frank Massa, assignor to Radio Corporation of America.
November 11, 1941, U.S.P.O. Cl. 181–0.5, 13 Claims.



2,268,130

5.10 METHOD OF GEOPHYSICAL INVESTIGATION

Morris M. Slotnick, assignor to Standard Oil Development Company.
December 30, 1941, U.S.P.O. Cl. 181–0.5, 1 Claim.



2,267,858

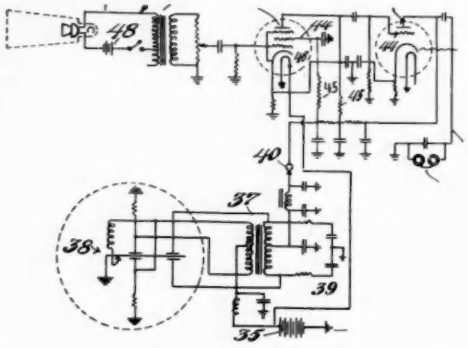
5.10 METHOD OF SEISMIC SURVEYING

Charles Hewitt Dix, assignor to Socony-Vacuum Oil Company, Inc.
December 30, 1941, U.S.P.O. Cl. 181–0.5, 2 Claims.

2,267,480

5.10 SOUND DIRECTION INDICATOR

Mancel W. Talcott.
December 23, 1941, U.S.P.O. Cl. 177–352, 2 Claims.

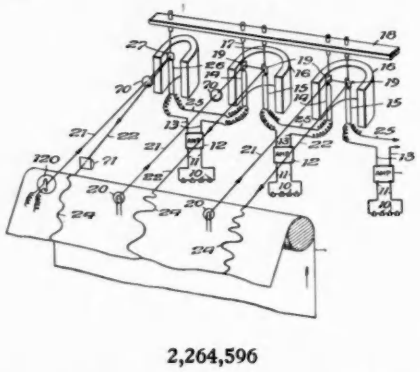


A device for determining the direction of an audible sound and is primarily for use on boats or aeroplanes.

2,267,356

5.10 APPARATUS FOR AND METHOD OF SEISMOGRAPH RECORDING

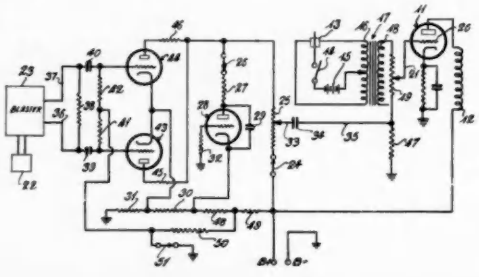
Otto F. Ritzmann, assignor to Gulf Research & Development Company.
December 23, 1941, U.S.P.O. Cl. 177–352, 13 Claims.



2,264,596

5.10 GEOPHYSICAL INSTRUMENT

Earley M. Shook and Robert W. Olson, assignors, by mesne assignments, to Socony-Vacuum Oil Company, Inc.
December 2, 1941, U.S.P.O. Cl. 181–0.5, 9 Claims.



2,266,837

5.10 METHOD AND APPARATUS FOR TRANSLATING SEISMIC WAVES

Harold F. Wiley, assignor, by mesne assignments, to Consolidated Engineering Corporation.
December 23, 1941, U.S.P.O. Cl. 181–0.5, 6 Claims.

2,265,513

5.10 PROSPECTING METHOD AND APPARATUS

Kenneth E. Burg, assignor to Geophysical Service, Inc.
December 9, 1941, U.S.P.O. Cl. 181–0.5, 3 Claims.

2,263,519

5.10 SEISMOGRAPH PROSPECTING APPARATUS

Otto F. Ritzmann, assignor to Gulf Research & Development Company.
November 18, 1941, U.S.P.O. Cl. 177–352, 7 Claims.

2,261,321

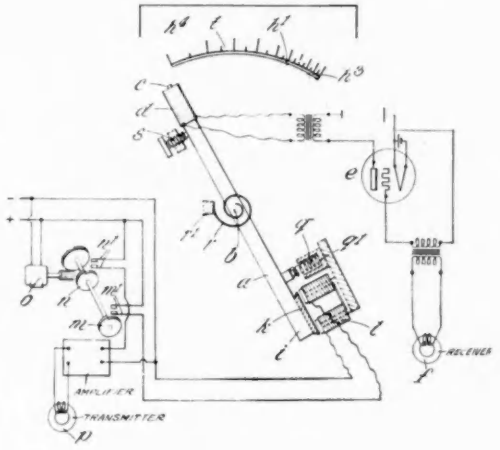
5.10 SEISMIC EXPLORATION METHOD

Philip S. Williams, assignor to Standard Oil Development Company.
November 4, 1941, U.S.P.O. Cl. 181–0.5, 9 Claims.

2,260,347

5.10 ECHO SOUNDING APPARATUS

Donald Orr Sproule, London, England, assignor of one-third to Henry Hughes & Son, Limited, London, and one-third to Arthur Joseph Hughes, Chigwell, Essex, England.
October 28, 1941, U.S.P.O. Cl. 177–386, 5 Claims.

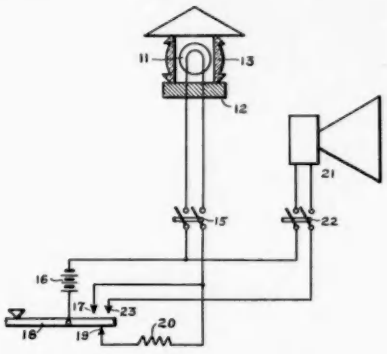


An apparatus for determination of altitude of aircraft.

2,252,849

5.10 LIGHT AND SOUND SIGNALING SYSTEM

John Hays Hammond, Jr.
August 19, 1941, U.S.P.O. Cl. 177–329, 1 Claim.

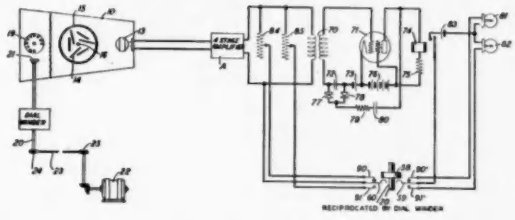


A combined sound signal and fog light.

2,261,573

5.15 NOISE LEVEL INDICATOR

Norman R. Stryker, assignor to Bell Telephone Laboratories, Incorporated.
November 4, 1941, U.S.P.O. Cl. 177–311, 7 Claims.

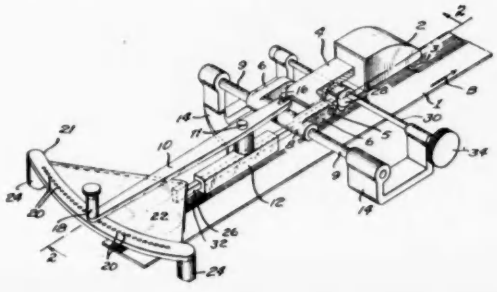


A sound level indicator for detecting and visually indicating excessive noise levels, or levels above a predetermined permissible limit.

2,259,631

5.16 SOUND RECORDING DEVICE

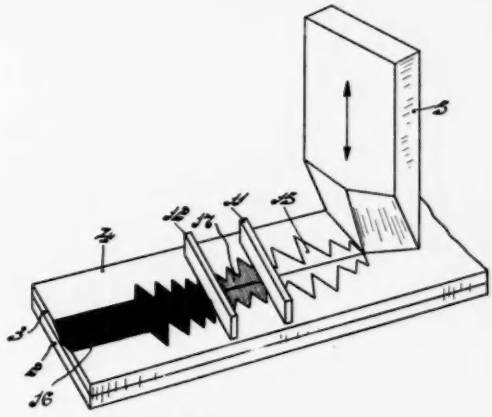
Henry Flood, Jr., assignor to Recordgraph Corporation.
October 21, 1941, U.S.P.O. Cl. 274–11, 13 Claims.



2,251,919

5.16 VIBRATION RECORD AND METHOD OF MAKING THE SAME

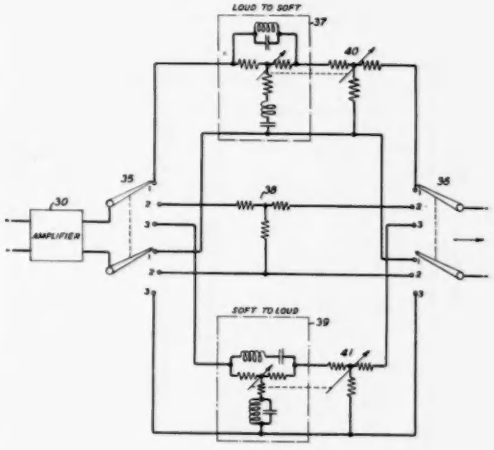
Jan Hendrik de Boer and Cornelis Johannes Dippel, Eindhoven, Netherlands, assignors by mesne assignments, to Hartford National Bank and Trust Company.
August 12, 1941, U.S.P.O. Cl. 274–46, 25 Claims.



2,253,186

5.16 SOUND CHARACTERISTIC CONTROL

Donald P. Loye and Kenneth F. Morgan, assignors to Electrical Research Products, Inc.
August 19, 1941, U.S.P.O. Cl. 179–1, 6 Claims.



2,264,008

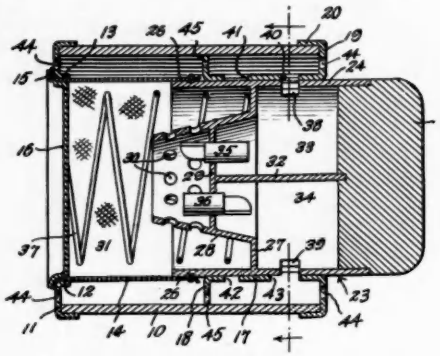
5.16 MAGNETIC SOUND RECORDING DEVICE

Arnold Stapelfeldt, Berlin, Germany, assignor to C. Lorenz Aktiengesellschaft, Berlin-Tempelhof, Germany.
November 25, 1941, U.S.P.O. Cl. 274–1, 10 Claims.

2,259,467

5.16 DEVICE FOR PRODUCING ARTICULATE SOUNDS

Beulah Louise Henry.
October 21, 1941, U.S.P.O. Cl. 46–187, 7 Claims.



Sound-producing device of the type which are utilized in dolls for emitting articulate sounds such as "ma-ma" and "pa-pa."

2,261,345

6.2 ELECTRICAL MUSICAL INSTRUMENT FOR PRODUCING BELL TONES

Galan W. Demuth, assignor to Radio Corporation of America.
November 4, 1941, U.S.P.O. Cl. 116–148, 2 Claims.

2,261,346

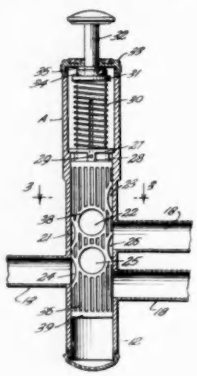
6.2 ELECTRIC CARILLON

Galan W. Demuth, assignor to Radio Corporation of America.
November 4, 1941, U.S.P.O. Cl. 84–405, 3 Claims.

2,260,723

6.3 PISTON VALVE FOR MUSICAL WIND INSTRUMENTS

Reginald B. Olds.
October 28, 1941, U.S.P.O. Cl. 84–388, 9 Claims.



2,261,119

6.4 KETTLE DRUM TUNING MECHANISM OR TYMPANO

William F. Ludwig and Cecil H. Strupe, assignors to W. F. Ludwig Drum Company.
November 4, 1941, U.S.P.O. Cl. 84–421, 14 Claims.

2,259,858

6.5 MUSICAL INSTRUMENT

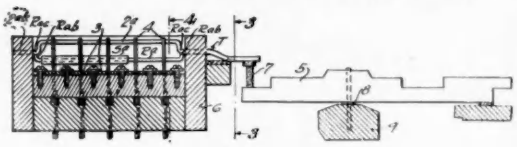
Ebenezer Emmet Reid.
October 21, 1941, U.S.P.O. Cl. 84–1.04, 10 Claims.

A musical instrument of the organ type.

2,261,999

6.5 CONTROL FOR ELECTRICALLY OPERATED PIPE ORGAN

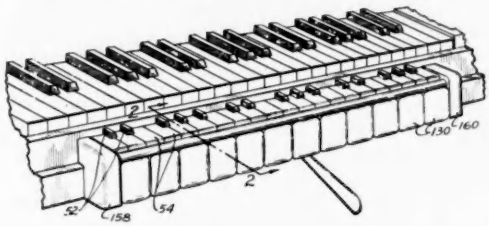
Max Hess.
November 11, 1941, U.S.P.O. Cl. 84–343, 9 Claims.

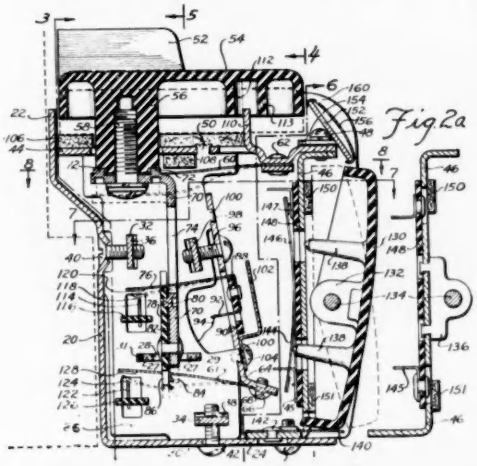


2,253,782

6.6 KEYBOARD FOR ELECTRICAL MUSICAL INSTRUMENTS

Laurens Hammond and George H. Stephens, assignors to Hammond Instrument Company.
August 26, 1941, U.S.P.O. Cl. 84–423, 13 Claims.

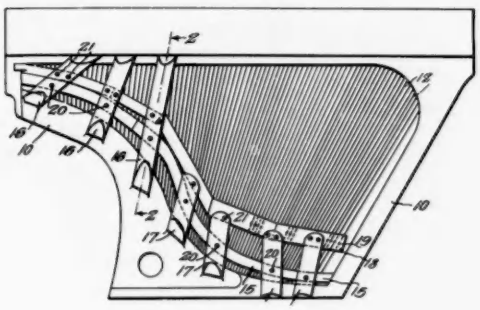




2,252,708

6.6 ELECTRIC PIANO CONSTRUCTION

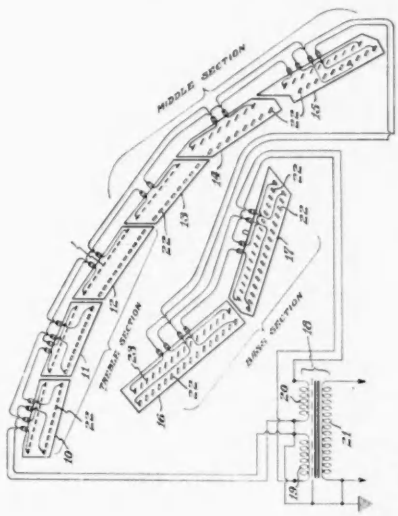
William L. Douden, assignor to Radio Corporation of America.
August 19, 1941, U.S.P.O. Cl. 84–1.15, 2 Claims.



2,258,990

6.6 ELECTRIC PIANO

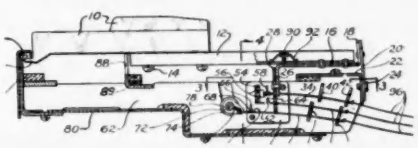
Ernest S. Lundie, assignor to Radio Corporation of America.
October 14, 1941, U.S.P.O. Cl. 84–1.15, 3 Claims.



2,260,412

6.6 KEY ACTION FOR MUSICAL INSTRUMENTS

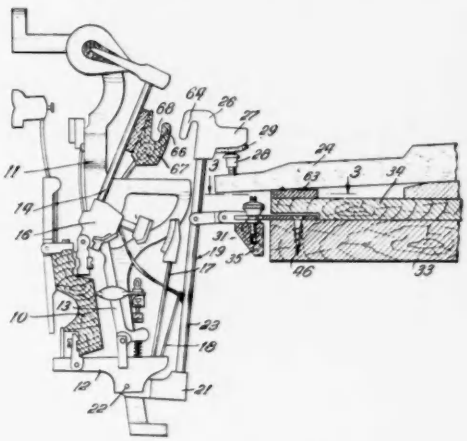
George H. Stephens, assignor to Hammond Instrument Company.
October 28, 1941, U.S.P.O. Cl. 84–423, 8 Claims.



2,260,287

6.6 PIANO ACTION

William G. Betz, assignor to Pratt, Read and Company.
October 28, 1941, U.S.P.O. Cl. 84–240, 11 Claims.



2,260,310

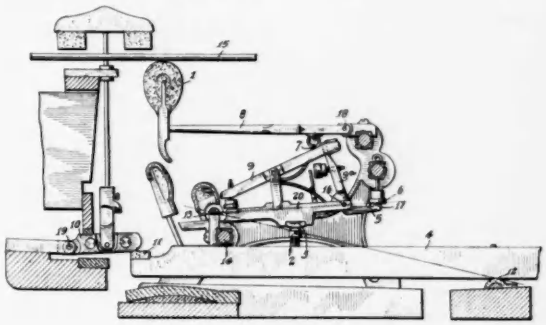
6.6 PIANO ACTION

James A. Gould, assignor to Pratt, Read and Company.
October 28, 1941, U.S.P.O. Cl. 84–240, 13 Claims.

2,263,088

6.6 PIANO ACTION

Josef Hofmann.
November 18, 1941, U.S.P.O. Cl. 84–239, 4 Claims.



2,260,335

6.6 PIANO ACTION

Julian C. Potwin, assignor to Pratt, Read and Company.
October 28, 1941, U.S.P.O. Cl. 84–240, 12 Claims.

2,263,839

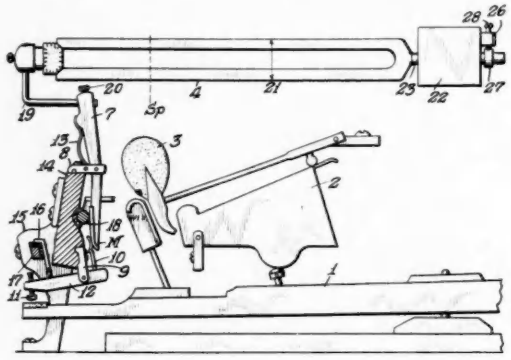
6.6 PIANO STRUCTURE

Cyril Farny, assignor to The Rudolph Wurlitzer Company.
November 25, 1941, U.S.P.O. Cl. 84–177, 7 Claims.

2,263,106

6.6 TUNING FORK PIANO

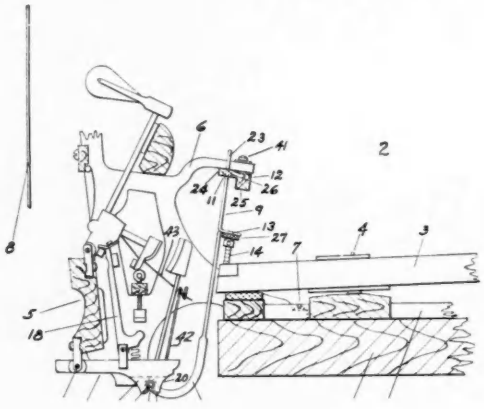
Dickran Sebouh.
November 18, 1941, U.S.P.O. Cl. 84–409, 3 Claims.



2,266,471

6.6 PIANO KEY AND ACTION CONNECTION

Arthur H. Morse, assignor to The Baldwin Company.
December 16, 1941, U.S.P.O. Cl. 84–240, 3 Claims.



2,266,690

6.6 PIANO ACTION

Lloyd Miller Martin.
December 16, 1941, U.S.P.O. Cl. 84–240, 15 Claims.

2,267,538

6.6 PIANO ACTION

Francis C. Socin, assignor to The Rudolph Wurlitzer Company.
December 23, 1941, U.S.P.O. Cl. 84–239, 4 Claims.

2,267,991

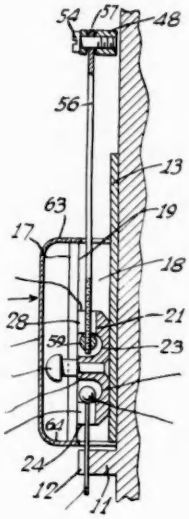
6.6 PRODUCING HARMONIC TONES IN PIANOS

Shinichi Ohkouchi, Sendai, Miyagi-ken, Japan.
December 30, 1941, U.S.P.O. Cl. 84–234, 4 Claims.

2,260,049

6.7 TUNING DEVICE FOR STRING INSTRUMENTS

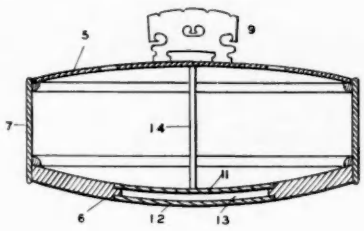
Frank J. Nickel, Jr.
October 21, 1941, U.S.P.O. Cl. 84–297, 5 Claims.



2,260,066

6.7 MUSICAL INSTRUMENT

Balthasar Vitalis.
October 21, 1941, U.S.P.O. Cl. 84–294, 2 Claims.

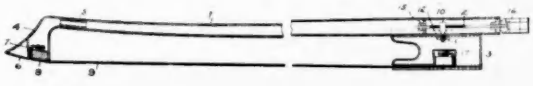


A device to be incorporated into the construction of instruments of the violin or similar instruments played with a bow.

2,263,793

6.7 BOW FOR MUSICAL STRINGED INSTRUMENTS

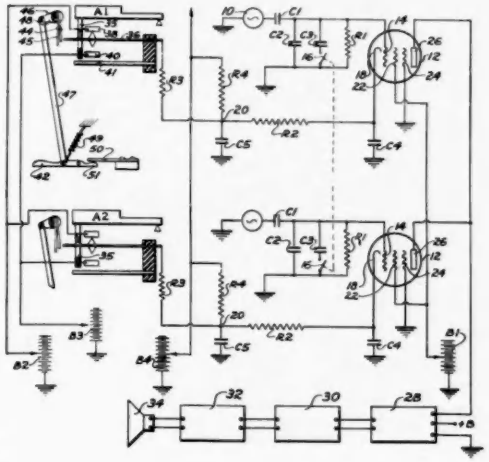
Fredrick Woerner.
November 25, 1941, U.S.P.O. Cl. 84–282, 3 Claims.



2,266,030

6.9 ELECTRICAL MUSICAL INSTRUMENT

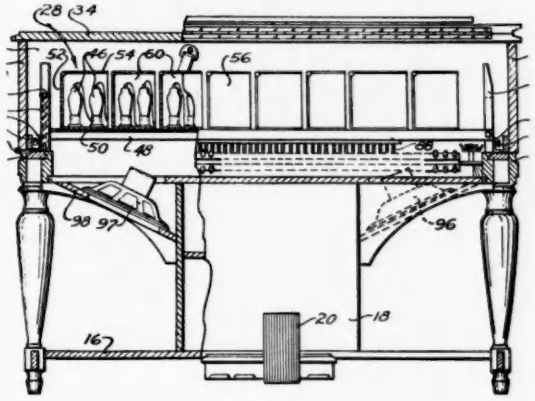
Laurens Hammond.
December 16, 1941, U.S.P.O. Cl. 84–1.26, 13 Claims.



2,262,179

6.9 MUSICAL INSTRUMENT

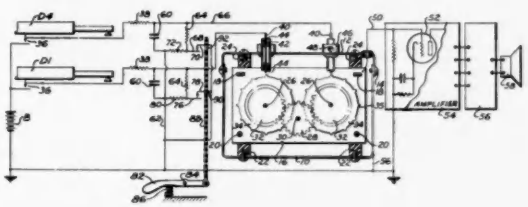
Laurens Hammond.
November 11, 1941, U.S.P.O. Cl. 84–177, 7 Claims.



2,262,494

6.9 ELECTRICAL MUSICAL INSTRUMENT

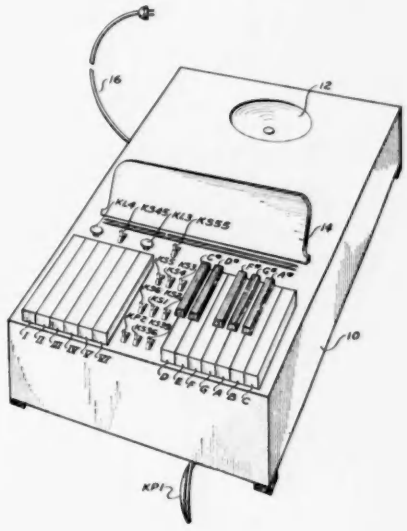
Laurens Hammond.
November 11, 1941, U.S.P.O. Cl. 84–1.26, 16 Claims.



2,254,284

6.9 ELECTRICAL MUSICAL INSTRUMENT

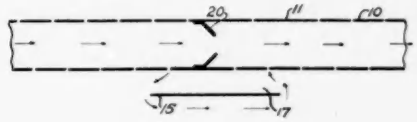
John M. Hanert, assignor to Hammond Instrument Company.
September 2, 1941, U.S.P.O. Cl. 84–1.19, 31 Claims.



2,253,693

7.7 MUFFLER

Floyd E. Deremer.
August 26, 1941, U.S.P.O. Cl. 181–48, 2 Claims.



2,259,516

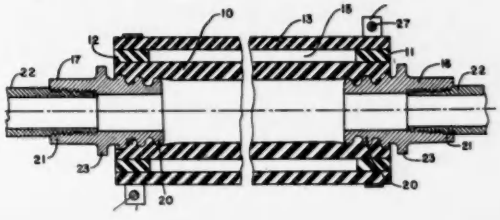
7.7 SILENCER CONSTRUCTION

Floyd E. Deremer.
October 21, 1941, U.S.P.O. Cl. 181–61, 1 Claim.

2,261,948

7.7 PIPE LINE NOISE ELIMINATOR

Ralph H. Beach, assignor to Gerotor May Company.
November 11, 1941, U.S.P.O. Cl. 285–90, 2 Claims.



2,264,524

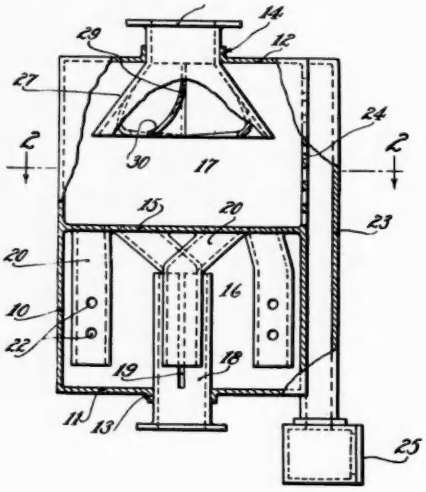
7.7 METHOD OF MAKING MUFFLERS

Adolph A. Hale.
December 2, 1941, U.S.P.O. Cl. 29–157.4, 1 Claim.

2,265,343

7.7 SPARK ARRESTER SILENCER

Roland B. Bourne, assignor to The Maxim Silencer Company.
December 9, 1941, U.S.P.O. Cl. 181–36, 3 Claims.



2,264,195

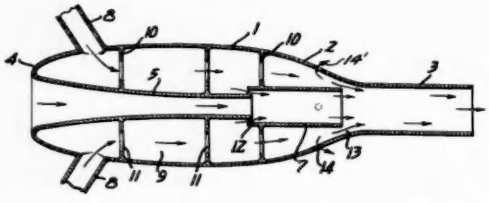
7.7 SILENCING DEVICE

Roland B. Bourne, assignor to The Maxim Silencer Company.
November 25, 1941, U.S.P.O. Cl. 181–57, 11 Claims.

2,264,765

7.7 MUFFLER

Harold E. Le Veque, assignor of one-half to Mary H. Littlefield.
December 2, 1941, U.S.P.O. Cl. 181–51, 9 Claims.



2,265,342

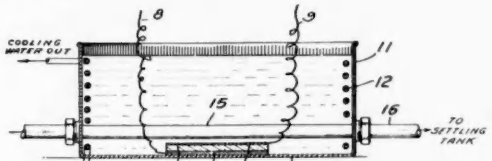
7.7 SILENCER

Roland B. Bourne, assignor to The Maxim Silencer Company.
December 9, 1941, U.S.P.O. Cl. 181–54, 10 Claims.

2,257,997

10.8 BREAKING PETROLEUM EMULSIONS

Robert Bowling Barnes, assignor to American Cyanamid Company.
October 7, 1941, U.S.P.O. Cl. 252–349, 11 Claims.

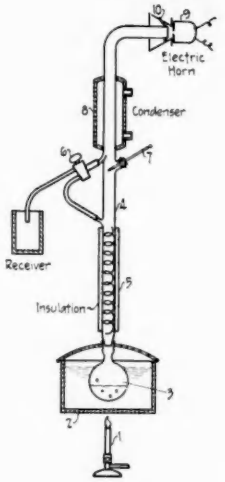


A method of breaking petroleum oil field emulsions of the water-in-oil type by subjecting the emulsion to the action of ultrasonic vibrations of the type generated by a quartz crystal when placed between the electrodes of a high frequency alternating current.

2,265,762

10.8 SEPARATION OF PHASES WITH THE AID OF SONIC WAVES

Donald S. McKittrick and Robert E. Cornish, assignors to Shell Development Company.
December 9, 1941, U.S.P.O. Cl. 202–39, 2 Claims.



A method for the fractionation of mixtures capable of separation by physical means, using sonic waves in the band of about 50 cycles per second to 500 megacycles per second.

Index to Volume 13

How to Use This Index

THIS Index is of similar form to the Cumulative Index of this journal, published in November, 1939, and is composed of two main divisions: The Author Index and the Subject Index.

The Subject Index to Volume 13 of *The Journal of the Acoustical Society of America* lists the titles of all the papers and abstracts under eleven section headings as follows: 1, Acoustical Society of America; 2, Architectural Acoustics; 3, Books and Bibliographies; 4, Ear and Hearing; 5, Applied Acoustics. Instruments and Apparatus; 6, Musical Instruments and Music; 7, Noise; 8, Standards; 9, Speech and Singing; 10, Supersonics; 11, Waves and Vibrations. Each of these sections is further divided into a considerable number of decimally numbered subjects, which are listed below under the heading, "Classification of Subjects." Each subject is divided into four parts entitled Papers, Subtitles, Abstracts, and Patents. Under Papers will be found the original titles of all the papers appearing in the journal on that subject. Under Abstracts are listed the titles of the papers presented at meetings. Since a great amount of valuable material appears in the journal in papers whose titles cannot fully describe all the subjects which the papers cover, many of the subtitles of papers have been indexed under the heading Subtitles. When subtitles covering the material did not appear in the paper, they were written; the captions of some of the figures were also included under this heading. Thus, while the Subtitles portion of the Index is informal, it is hoped that it will increase the probability of finding the desired information quickly. All patents appearing in the journal are listed under the heading Patents.

References on most subjects can be located immediately by a logical use of the Classification of Subjects below. In case the reference sought is of an unusual character such that there is uncertainty as to the subject under which it might have been classified, this can usually be found quite quickly by the process of eliminating the sections and subjects under which it is quite improbable that it might have been listed. In case of doubt, a title has often been listed under a number of subjects. As an example of the direct approach, suppose you wish to find data on the absorption coefficients for hairfelt. On looking over the section headings it is seen that this comes under the heading Architectural Acoustics, and Subject, Measured Sound Absorption Coefficients. Under Subtitles we find a reference to hairfelt, and on looking up this paper we find it entitled "The Acoustic Wattmeter, an Instrument for Measuring Sound Energy Flow," which title of itself would not have suggested the presence of data on hairfelt, thus demonstrating the value of having the index of Subtitles.

Obviously, the Author Index is more convenient than the Subject Index when one knows the name of the author of the paper in which he is interested.

The References to Contemporary Papers on Acoustics are identified in each issue by the same decimal numbers listed below, and may be consulted for references in other journals than our own. In Volume 13 these references will be found on pages 71, 194, 323 and 395.

Classification of Subjects

	Page in this Index
1. Acoustical Society of America	
1.1 General, Unclassified	416
1.5 Acoustical Society News	416
1.6 Members and Membership Lists	416
2. Architectural Acoustics	
2.1 General, Unclassified	416
2.2 Auditorium Design (see also 7.6)	416
2.4 Sound Absorption, Theory and Methods of Measurement (see also 2.5 and 2.7)	416
2.5 Measured Sound Absorption Coefficients (see also 2.4)	417
2.6 Noise Reduction by Increased Room Absorption	417
2.7 Reverberation, Theory and Calculation of (see also 2.4, 2.9 and 2.10)	417
2.9 Sound Transmission, Theory and Methods of Measurement (see also 2.7 and 2.10)	417
2.11 Vibration Insulating Supports	417
3. Books and Bibliographies	
3.1 Book Reviews	417
4. Ear and Hearing	
4.1 General, Unclassified	417
4.2 Anatomy and Physiology of the Ear	418
4.3 Binaural Hearing. Localization	418
4.4 Deafness	418
4.5 Instruments Relating to Hearing	418
4.7 Masking	418
4.9 Pitch	418
4.10 Subjective Tones	418

Page in this Index

5. Applied Acoustics, Instruments and Apparatus

5.1 General, Unclassified 419
5.3 Acoustical Impedance Measurement (see also 11.4) 419
5.4 Analyzers and Filters. Acoustic Filters. Oscillographs (see also 5.15) 419
5.5 Audiometers 419
5.51 Broadcasting 419
5.7 Frequency Standards. Frequency Measuring and Recording Instruments 419
5.8 Loudspeakers, Horns (see also 5.13 and 5.17) 419
5.9 Microphones, Vibration Microphones, and Microphone Calibration Equipment 419
5.10 Navigational Instruments. Depth and Altitude Finding Instruments. Geophysical Prospecting. Under-Water Sound. Submarine Detectors 420
5.15 Sound Level Meters. Level Recorders. Sound Pressure Measurement (see also 5.4 and 7.1) 420
5.16 Sound Recording and Reproducing (see also 5.13) 420
5.17 Telephone Receivers (see also 5.8) 421
5.19 Tuning Forks 421

6. Musical Instruments and Music

6.1 General, Unclassified 421
6.2 Bells 421
6.3 Brass 421
6.4 Drums and Traps 421
6.5 Organs (see also 6.9) 421
6.6 Pianos 421
6.7 Violin Family 422
6.9 Electronic Musical Instruments (see also 6.5) 422

Page in this Index

7. Noise

7.4 City Noise 422
7.6 Noise in Buildings 422
7.7 Machinery Noise 422

8. Standards

8.1 General, Unclassified 422

9. Speech and Singing

9.1 General, Unclassified 423
9.6 Instruments Relating to Speech and Singing 423

10. Supersonics (Ultrasonics)

10.1 General, Unclassified 423
10.3 Supersonic Instruments 423
10.4 Gases, Supersonic Velocities, Dispersion, and Absorption (see also 11.3) 423
10.5 Liquids, Supersonic Velocities, Dispersion, and Absorption 423
10.8 Chemical Effects of Supersonic Waves 423
10.9 Biological Effects of Supersonic Waves 423

11. Waves and Vibrations

11.3 Propagation of Sound. Absorption during Propagation. Velocity of Sound (see also 10.4) 423
11.4 Radiation from Vibrating Objects. Acoustical Impedance. Mechanical Impedance (see also 5.3) 423
11.6 Sound Transmission Through Tubes 423
11.7 Theory of Waves and Vibrating Systems 423

Author Index to Volume 13

Numerals in bold face type refer to volume numbers. (A) designates abstracts; (T) designates title only.

Abbott, R. B. and G. H. Purcell. Physical properties of wood for violin construction. **13:** 54—1941

Albersheim, W. J. Book review. **13:** 321—1942

Alleman, Ray S. Heat conduction effects in sound emission. **13:** 23—1941

Anderson, A. B. (see Wente, E. C.) **13:** 85(A), 100—1941

Balbi, Charles M. R. Basis for the prediction of performance of deaf aids. **13:** 335(A)—1942

Bartholomew, Wilmer T. High fidelity from the musician's viewpoint. **13:** 331(A)—1942

Bauer, Benjamin B. Uniphase unidirectional microphones. **13:** 41—1941

Begun, S. J. and T. E. Lynch. Correlation between elastic deformation and vertical forces in lateral recording. **13:** 284—1942; Erratum. **13:** 392—1942

—— Influence of elastic properties of disk material upon the "pinch-effect" in lateral recording. **13:** 330(A)—1942

Beranek, Leo L. Acoustic impedance of porous materials. **13:** 248—1942

Biddulph, R. (see Wente, E. C.) **13:** 85(A), 86(A), 100—1941

Bolt, Richard H. (see Brown, Richard L.) **13:** 337—1942

——, **A. M. Clogston and H. Feshbach.** On the perturbation of normal modes of vibration. **13:** 82(A)—1941

Boner, C. P. Performance of broadcast studios designed with convex surfaces of plywood. **13:** 244, 334(A)—1942

—— (see Nolle, A. W.) **13:** 145, 149—1941; 333(A)—1942

Bonvallet, G. L. Problem in acoustically treated enclosures. **13:** 87(A)—1941

Bouman, H. D. Experiments on short tones. **13:** 84(A)—1941

Bray, Charles W. (see Wever, Ernest Glen) **13:** 83(A), 182—1941; 334(A)—1942

—— **and W. R. Thurlow.** Temporary deafness in birds. **13:** 335(A)—1942

Brown, Richard L. and Richard H. Bolt. Measurement of flow resistance of porous acoustic materials. **13:** 337—1942

—— **and Philip M. Morse.** Sound absorption coefficients and acoustic impedance. **13:** 82(A)—1941

Brown, W. N., Jr. Theory of conical sound radiators. **13:** 20—1941

Buhl, Walter T. Ball bearing noise and vibration. **13:** 51—1941

Burris-Meyer, Harold. Theatrical uses of the remade voice, subsonics and reverberation control. **13:** 16, 80(A)—1941

Clapp, C. W. and F. A. Firestone. Acoustic wattmeter, an instrument for measuring sound energy flow. **13:** 124—1941

Clogston, A. M. (see Bolt, R. H.) **13:** 82(A)—1941

Coakley, J. D. Synchronization in the higher auditory pathways. **13:** 84(A)—1941

Cook, Guy S. and Richard K. Cook. Absolute calibration of microphones. **13:** 81(A)—1941

Cook, Richard K. (see Cook, Guy S.) **13:** 81(A)—1941

Cowan, J. M. Duration thresholds for the perception of certain transient phenomena (review). **13:** 65—1941

—— Errors in light band width measurements on phonograph records (review). **13:** 190—1941

Culler, E. A. Demonstration of animal experiments. **13:** 85(T)—1941

Elmer, L. A. Non-cinching film-rewind machine. **13:** 86(A)—1941

—— (see Wente, E. C.) **13:** 85(A), 100—1941

Erf, Herbert A. Review of acoustical patents. **13:** 74, 197—1941; 326, 399—1942

Feshbach, H. (see Bolt, R. H.) **13:** 82(A)—1941

Firestone, F. A. Book reviews. **13:** 71—1941; 322, 395—1942

—— Current publications on acoustics. **13:** 65, 189—1941; 320, 395—1942

—— (see Clapp, C. W.) **13:** 124—1941

Fletcher, Harvey. Stereophonic sound film system—general theory. **13:** 85(A), 89—1941

Ford, Adelbert. Dynamic auditory localization. 1. The binaural intensity disparity limen. **13:** 367—1942

Fowler, Edmund Prince. Method for measuring the percentage of capacity for hearing speech. **13:** 335(A), 373—1942

Goldsmith, F. H. Noise and wear reducing phonograph reproducer with controlled response. **13:** 281, 330(A)—1942

Hardy, H. C. (see Pielemeier, W. H.) **13:** 80(A)—1941

——, **D. Telfair and W. H. Pielemeier.** Velocity of sound in air. **13:** 226—1942

Haynes, J. R. Apparatus for the direct measurement of force-displacement characteristics of mechanical systems at audiofrequencies. **13:** 332(A)—1942

Herzfeld, Karl F. Origin of the absorption of ultrasonic waves in liquids. **13:** 33—1941

Hubbard, J. C. Book review. **13:** 321—1942

Hunter, Joseph Lawrence. Absorption of ultrasonic waves in highly viscous liquids. **13:** 36—1941

Jack, W. A. (see Parkinson, J. S.) **13:** 83(A), 163—1941

Johnson, Parker (see Kemp, E. H.) **13:** 87(A)—1941

Jordan, Edward C. Continuously variable acoustic impedance. **13:** 8—1941

Josephson, Emanuel M. Altered acoustical resonance of the external auditory canal as a factor in the transient improvement of hearing obtained by fenestration operations in chronic progressive deafness. **13:** 83(A)—1941

Kemp, E. H. and Parker Johnson. Localization of response in the cochlea as determined by electrical recording. **13**: 87(A)—1941
Kendall, H. C. (see Overbeck, C. J.) **13**: 26—1941
Klipsch, Paul W. Low frequency horn of small dimensions. **13**: 137—1941
Knauss, H. P. and W. J. Yeager. Vibration of the walls of a cornet. **13**: 160—1941
Knowles, Hugh S. System concept of electroacoustical systems. **13**: 81(A)—1941
Kobrak, H. G. Cinematographic study of the conduction of sound in the human ear. **13**: 179—1941
—— Study of sound conduction in the human ear (a motion picture). **13**: 83(A)—1941
Kranz, Fred W. and Carl E. Rudiger. Relation of audiogram measurements to hearing aid characteristics based on commercial experience. **13**: 335(A), 363—1942

Labaw, Louis W. Acoustic filtration by membranes. **13**: 333(A), 353—1942
—— Acoustic filtration in parallel conduit structures. **13**: 345—1942
La Prade, Ernest. High fidelity from the musician's viewpoint. **13**: 331(A)—1942
Lawrence, Merle (see Wever, Ernest Glen) **13**: 83(A), 182—1941
LeBel, C. J. Properties of the dulled lacquer cutting stylus. **13**: 265, 330(A)—1942
Leedy, H. A. Greater Chicago noise survey. **13**: 332(A)—1942
Lewis, Don. Pitch and the missing fundamental. **13**: 84(A)—1941
—— (Chairman). Round table discussion on distortion in the ear. **13**: 85(T)—1941
Lindenberg, Theodore, Jr. Phonograph pick-up of the moving coil type. **13**: 330(A)—1942
Little, George P. and F. Edgar McGee. Report of activities of the National Noise Abatement Council. **13**: 211, 331(A)—1942
Lloyd, Llewelyn S. Musical theory in retrospect. **13**: 56—1941
Louden, W. C. (see Stahl, M. D.) **13**: 9—1941
Lowy, Karl. Change of phase caused by impedance deafness. **13**: 389—1942
—— Electrical response of the auditory nerve to different sound intensities under pathological conditions. **13**: 83(A)—1941
—— Experiment on middle ear deafness. **13**: 334(A)—1942
—— Experiments on the pellet-type of artificial drum. **13**: 383—1942
Loye, D. P. and R. L. Morgan. Acoustic tube for measuring the sound absorption coefficients of small samples. **13**: 261, 334(A)—1942
Lynch, T. E. (see Begun, S. J.) **13**: 284, 330(A), 392—1942
Lynn, R. A. Discussion of several factors contributing to good recording. **13**: 331(A)—1942

Maa, D. Y. Flutter echoes. **13**: 170—1941
Martin, Daniel W. Directivity and the acoustic spectra of brass wind instruments. **13**: 309, 333(A)—1942
—— Lip vibrations in a cornet mouthpiece. **13**: 80(A)—1941; 305—1942
McGee, F. Edgar (see Little, George P.) **13**: 211, 331(A)—1942
McMath, R. R. Solar prominences in motion. **13**: 87(T)—1941
Morgan, C. T. (see Stevens, S. S.) **13**: 84(A)—1941
Morgan, R. L. (see Loye, D. P.) **13**: 261, 334(A)—1942
Morse, Philip M. (see Brown, Richard L.) **13**: 82(A)—1941
Müller, A. H. (see Wente, E. C.) **13**: 86(A)—1941

Neergaard, Charles, F. What can the hospital do about noise? **13**: 217, 332(A)—1942
Nolle, A. W. and C. P. Boner. Harmonic relations in the partials of organ pipes and of vibrating strings. **13**: 145—1941
—— **and C. P. Boner.** Initial transients of organ pipes. **13**: 149—1941
—— **and C. P. Boner.** Some aspects of the transient and steady state tones of organ pipes and of vibrating strings. **13**: 333(A)—1942
Norling, J. A. Progress in three-dimensional photography. **13**: 87(T)—1941

Overbeck, C. J. and H. C. Kendall. Temperature and frequency effects on ultrasonic velocities in carbon dioxide. **13**: 26—1941

Parkinson, J. S. Effect of high intensity noise levels on surrounding areas. **13**: 332(A)—1942
—— **and W. A. Jack.** Re-examination of the noise reduction coefficient. **13**: 83(A), 163—1941
Peabody, Ernest H. History of noise abatement in New York City. **13**: 332(A)—1942
Pielemeier, W. H. (see Hardy, H. C.) **13**: 226—1942
—— **and H. C. Hardy.** Corrections on the measurements of the velocity of sound in gases. **13**: 80(A)—1941
Purcell, G. H. (see Abbott, R. B.) **13**: 54—1941

Reid, John D. Large radius stylus for the reproduction of lateral cut phonograph records. **13**: 274, 330(A)—1942
Roe, Glenn M. Frequency distribution of normal modes. **13**: 1—1941
Romanow, Frank F. Methods for measuring the performance of hearing aids. **13**: 294—1942
Rosenblith, Walter A. Industrial noises and industrial deafness. **13**: 80(A)—1941; 220—1942
Rudiger, Carl E. (see Kranz, Fred W.) **13**: 335(A), 363—1942
Russell, G. Oscar. Book review. **13**: 70—1941

Sabine, Paul E. Acoustical Society and noise abatement. **13**: 207, 332(A)—1942
—— Bibliography on noise. **13**: 210—1942
—— Book review. **13**: 193—1941
Schuck, O. H. (see Young, R. W.) **13**, 191—1941
—— **and R. W. Young.** Demonstration of the chromatic stroboscope as a general purpose frequency meter. **13**: 82(A)—1941

Scott, H. H. Analyzer for sub-audible frequencies. **13:** 334(A), 360—1942
—— General purpose vibration meter. **13:** 46, 82(A)—1941
Sepmeyer, Ludwig W. Tracing distortion in the reproduction of constant amplitude recordings. **13:** 80(A)—1941; 276—1942
Snow, W. B. and A. R. Soffel. Electrical equipment for the stereophonic sound-film system. **13:** 86(A)—1941
Soffel, A. R. (see Snow, W. B.) **13:** 86(A)—1941
Stahl, M. D. and W. C. Louden. Sound measurement room utilizing the live end-dead end studio principle. **13:** 9—1941
Steinberg, John C. Stereophonic sound film system—pre- and post-equalization of compandor systems. **13:** 86(A), 107—1941
Stevens, S. S., C. T. Morgan and J. Volkmann. Evidences for a neural quantum in auditory discrimination. **13:** 84(A)—1941

Telfair, D. (see Hardy, H. C.) **13:** 226—1942
Thurlow, W. R. (see Bray, Charles W.) **13:** 335(A)—1942
Townsend, C. L. Contemporary problems in television sound. **13:** 334(A)—1942

Volkmann, John E. Polycylindrical diffusers in room acoustic design. **13:** 234, 334(A)—1942
—— (see Stevens, S. S.) **13:** 84(A)—1941

Watson, L. A. Some considerations relative to the calibration of bone-conduction receivers for audiometers. **13:** 336(A)—1942
Watson, Norman, A. Hearing aids: uniform and selective: monaural, diotic and binaural; air and bone conduction. **13:** 335(A)—1942
Watson, R. B. Modulation of sound decay curves. **13:** 82(A)—1941
Wente, E. C. and R. Biddulph. Light valve for the stereophonic sound-film system. **13:** 86(A)—1941
—— **and A. H. Müller.** Internally damped rollers. **13:** 86(A)—1941
——, **R. Biddulph, L. A. Elmer and A. B. Anderson.** Mechanical and optical equipment for the stereophonic sound film system. **13:** 85(A), 100—1941
Wever, Ernest Glen and Charles W. Bray. Stapedius muscle in relation to the conduction of sound to the inner ear. **13:** 334(A)—1942
——, **Charles W. Bray and Merle Lawrence.** Effect of middle ear pressure upon distortion. **13:** 182—1941
——, **Charles W. Bray and Merle Lawrence.** Effects of pressure in the middle ear upon the electrical responses of the cochlea. **13:** 83(A)—1941
White, William Braid. Contribution offered towards a discussion of the paper "Pitch and the missing fundamental." **13:** 87(A)—1941
Wiener, Francis M. Phase distortion in electroacoustic systems. **13:** 81(A), 115—1941; Erratum. **13:** 317—1942
Wiesner, Jerome B. Recording laboratory in the Library of Congress. **13:** 288, 331(A)—1942
Winston, Matie E. Appeal to science for specialized hearing aids of true selective amplification. **13:** 335(A)—1942
Wolf, S. K. Acoustic experiments with an electronic switch. **13:** 332(A)—1942
—— Production and control of acoustic characteristics. **13:** 81(A)—1941
Woodward, J. G. Resonance characteristics of a cornet. **13:** 156—1941
Wynne, Shirley W. City noise. **13:** 214, 331(A)—1942

Yeager, W. J. (see Knauss, H. P.) **13:** 160—1941
Young, Robert W. Some characteristics of the tuning of valved wind instruments. **13:** 333(A)—1942
—— Steady circulations in the Kundt's tube (review). **13:** 320—1942
—— Tone spectrum of a Silbermann organ (review). **13:** 189—1941
—— (see Schuck, O. H.) **13:** 82(A)—1941
—— **and O. H. Schuck.** Novel, highly effective sound-absorbing arrangement and the construction of a dead room (review). **13:** 191—1941

Analytic Subject Index to Volume 13

Numerals in bold face type refer to volume numbers.

1. Acoustical Society of America

1.1 General, Unclassified

Biennial award for noteworthy contributions to acoustics. **13**: 315—1942

Civil Service examinations for scientists reannounced. **13**: 393—1942

National science fund. **13**: 393—1942

Notice to physicists. **13**: 315—1942

1.5 Acoustical Society News

Future meetings. **13**: 393—1942

1.6 Members and Membership Lists

Letter from Mrs. Dayton C. Miller. **13**: 188—1941

Members elected to fellowship—May 6, 1941. **13**: 63—1941

New members. **13**: 63, 188—1941; 315, 394—1942

Obituary notice of Charles C. Potwin. **13**: 319—1942

Photograph of Charles C. Potwin. **13**: 318—1942

Photograph of F. A. Saunders. **13**: 314—1942

Photograph of F. R. Watson. **13**: 314—1942

Two past presidents of the Acoustical Society retire from their universities. **13**: 314—1942

2. Architectural Acoustics

2.1 General, Unclassified

PAPERS

Flutter echoes. D. Y. Maa. **13**: 170—1941

Frequency distribution of normal modes. Glenn M. Roe. **13**: 1—1941

Sound measurement room utilizing the live end-dead end studio principle. M. D. Stahl and W. C. Louden. **13**: 9—1941

ABSTRACTS

Acoustics. A handbook for architects and engineers Percy L. Marks (book review). **13**: 193—1941

Acoustics of buildings. F. R. Watson (book review) **13**: 322—1942

PATENTS

Acoustical correction machine. **13**: 75—1941

Process of increasing the sound absorptive properties of cellular glass. **13**: 74—1941

Telephone booth. **13**: 197—1941

2.2 Auditorium Design (see also 7.6)

PAPERS

Performance of broadcast studios designed with convex surfaces of plywood. C. P. Boner. **13**: 244—1942

Polycylindrical diffusers in room acoustic design. John E. Volkmann. **13**: 234—1942

Theatrical uses of the remade voice, subsonics and reverberation control. Harold Burris-Meyer. **13**: 16—1941

SUBTITLE

Preferred room dimensions. John E. Volkmann. **13**: 238—1942

ABSTRACTS

Performance of broadcast studios designed with convex surfaces of plywood. C. P. Boner. **13**: 334—1942

Polycylindrical diffusers in room acoustic design. John E. Volkmann. **13**: 334—1942

Production and control of acoustic characteristics. S. K. Wolf. **13**: 81—1941

Theatrical uses of the remade voice, subsonics and reverberation control. Harold Burris-Meyer. **13**: 80—1941

PATENTS

Acoustic device. **13**: 326—1942

Acoustical assembly. **13**: 399—1942

Sound arrester at the opening of sound-arresting room. **13**: 75—1941

2.4 Sound Absorption, Theory and Methods of Measurement (see also 2.5 and 2.7)

PAPERS

Acoustic impedance of porous materials. Leo L. Beranek. **13**: 248—1942

Acoustic tube for measuring the sound absorption coefficients of small samples. D. P. Loye and R. L. Morgan. **13**: 261—1942

Continuously variable acoustic impedance. Edward C. Jordan. **13**: 8—1941

Heat conduction effects in sound emission. Ray S. Alleman. **13**: 23—1941

Measurement of flow resistance of porous acoustic materials. Richard L. Brown and Richard H. Bolt. **13**: 337—1942

Re-examination of the noise reduction coefficient. J. S. Parkinson and W. A. Jack. **13**: 163—1941

SUBTITLES

Apparatus for measuring the flow resistance of acoustical materials. Leo L. Beranek. **13**: 254—1942

Apparatus for measuring the porosity of acoustical materials. Leo L. Beranek. **13**: 255—1942

ABSTRACTS

Acoustic tube for measuring the sound absorption coefficients of small samples. D. P. Loye and R. L. Morgan. **13**: 334—1942

Novel, highly effective sound-absorbing arrangement and the construction of a dead room. E. Meyer, G. Buchmann and A. Schöch (Akustische Zeits. **5**, 352–364 (1940)). **13**: 191—1941

Sound absorption coefficients and acoustic impedance. Richard L. Brown and Philip M. Morse. **13**: 82—1941

PATENTS

Acoustic material. **13**: 197—1941

Composition of matter. **13**: 399—1942
Manufacture of artificial stones with high porosity. **13**: 197—1941

2.5 Measured Sound Absorption Coefficients (see also 2.4)

PAPER

Acoustic impedance of porous materials. Leo L. Beranek. **13**: 248—1942

SUBTITLES

Absorption coefficients for Acousti-Cellotex. C. W. Clapp and F. A. Firestone. **13**: 136—1941
Absorption coefficients for hairfelt. C. W. Clapp and F. A. Firestone. **13**: 135—1941
Celotex C-4. Leo L. Beranek. **13**: 259—1942
Fibreglas insulating board. Leo L. Beranek. **13**: 256—1942
Fibreglass P. F. insulating board. Leo L. Beranek. **13**: 259—1942
Fibretex. Leo L. Beranek. **13**: 259—1942
Kapok. Leo L. Beranek. **13**: 258—1942
1" rigid rock wool sheet (Celotex). Leo L. Beranek. **13**: 260—1942
Permacoustic. Leo L. Beranek. **13**: 259—1942
QT ductliner (Celotex). Leo L. Beranek. **13**: 257—1942
U. S. G. perafatone pad. Leo L. Beranek. **13**: 258—1942

2.6 Noise Reduction by Increased Room Absorption

PAPER

Re-examination of the noise reduction coefficient. J. S. Parkinson and W. A. Jack. **13**: 163—1941

ABSTRACT

Re-examination of the noise reduction coefficient. J. S. Parkinson and W. A. Jack. **13**: 83—1941

2.7 Reverberation, Theory and Calculation of (see also 2.4, 2.9 and 2.10)

PAPERS

Frequency distribution of normal modes. Glenn M. Roe. **13**: 1—1941
Theatrical uses of the remade voice, subsonics and reverberation control. Harold Burris-Meyer. **13**: 16—1941

ABSTRACTS

Modulation of sound decay curves. R. B. Watson. **13**: 82—1941
On the perturbation of normal modes of vibration. R. H. Bolt, A. M. Clogston and H. Feshback. **13**: 82—1941

2.9 Sound Transmission, Theory and Methods of Measurement (see also 2.7 and 2.10)

ABSTRACT

Problem in acoustically treated enclosures. G. L. Bonvallet. **13**: 87—1941

PATENTS

Apparatus for preventing or diminishing sound transmission. **13**: 76—1941
Fluid silencer. **13**: 75—1941
Laminated insulation structure. **13**: 76—1941
Sound and vibration insulation for aircraft cabins. **13**: 399—1942
Sound deadener. **13**: 75—1941
Sound-deadening composition and the process of preparing same. **13**: 75—1941
Soundproof wall structure. **13**: 399—1942

2.11 Vibration Insulating Supports

PATENTS

Damping means. **13**: 198—1941
Engine unit mounting. **13**: 198—1941
Flexible supporting arrangement. **13**: 400—1942
Machine and supporting arrangement therefore. **13**: 198—1941
Means for isolating machinery. **13**: 326—1942
Resilient mounting. **13**: 327, 399—1942
Resilient support. **13**: 197—1941
Shock and vibration proof mounting for control apparatus. **13**: 198—1941
Vibration dampening device. **13**: 399—1942
Vibration dampening fitting. **13**: 400—1942
Vibration damping means. **13**: 400—1942
Vibration isolation base for motorized fans and the like. **13**: 400—1942

3. Books and Bibliographies

3.1 Book Reviews

Acoustics. Alexander Wood. **13**: 71—1941
Acoustics. A handbook for architects and engineers. Percy L. Marks. **13**: 193—1941
Acoustics of buildings. F. R. Watson. **13**: 322—1942
Automatic record changers and recorders. John F. Rider. **13**: 395—1942
Dictionary of radio and television terms. Ralph Stranger. **13**: 395—1942
Grundlagen und Ergebnisse der Ultraschallforschung. Egon Hiedemann. **13**: 321—1942
Hearing aids. Fred W. Kranz. **13**: 322—1942
Musical acoustics. Charles C. Culver. **13**: 322—1942
Physik und Technik des Tonfilms (Physics and technique of sound films). Hugo Lichte and Albert Narath. **13**: 321—1942
Voice, its production and reproduction. Douglas Stanley and J. P. Maxfield. **13**: 70—1941

4. Ear and Hearing

4.1 General, Unclassified

PAPERS

Cinematographc study of the conduction of sound in the human ear. H. G. Kobrak. **13**: 179—1941
Effect of middle ear pressure upon distortion. Ernest Glen Wever, Charles W. Bray and Merle Lawrence. **13**: 182—1941
Method for measuring the percentage of capacity for hearing speech. Edmund Prince Fowler. **13**: 373—1942

ABSTRACTS

Duration thresholds for the perception of certain transient phenomena. W. Türk (Akustische Zeits. **5**, 129–145 (1940)). **13**: 65—1941

Effects of pressure in the middle ear upon the electrical responses of the cochlea. Ernest Glen Wever, Charles W. Bray and Merle Lawrence. **13**: 83—1941

Experiments on short tones. H. D. Bouman. **13**: 84—1941

Stapedius muscle in relation to the conduction of sound to the inner ear. Ernest Glen Wever and Charles W. Bray. **13**: 334—1942

Study of sound conduction in the humn ear. (A motion picture.) H. G. Kobrak. **13**: 83—1941

Synchronization in the higher auditory pathways. J. D. Coakley. **13**: 84—1941

4.2 Anatomy and Physiology of the Ear

ABSTRACTS

Evidences for a neural quantum in auditory discrimination. S. S. Stevens, C. T. Morgan and J. Volkmann. **13**: 84—1941

Localization of response in the cochlea as determined by electrical recording. E. H. Kemp and Parker Johnson. **13**: 87—1941

4.3 Binaural Hearing. Localization

PAPER

Dynamic auditory localization. 1. The binaural intensity disparity limen. Adelbert Ford. **13**: 367—1942

4.4 Deafness

PAPERS

Change of phase caused by impedance deafness. Karl Lowy. **13**: 389—1942

Industrial noises and industrial deafness. Walter Rosenblith. **13**: 220—1942

Relation of audiogram measurements to hearing aid characteristics based on commercial experience. Fred W. Kranz and Carl E. Rudiger. **13**: 363—1942

ABSTRACTS

Altered acoustical resonance of the external auditory canal as a factor in the transient improvement of hearing obtained by fenestration operations in chronic progressive deafness. Emanuel M. Josephson. **13**: 83—1941

Electrical response of the auditory nerve to different sound intensities under pathological conditions. K. Lowy. **13**: 83—1941

Experiment on middle ear deafness. Karl Lowy. **13**: 334—1942

Industrial noises and industrial deafness. W. A. Rosenblith. **13**: 80—1941

Method for measuring the percentage of capacity for hearing speech. Edmund Prince Fowler. **13**: 335—1942

Temporary deafness in birds. Charles W. Bray and W. R. Thurlow. **13**: 335—1942

4.5 Instruments Relating to Hearing

PAPERS

Experiments on the pellet-type of artificial drum. Karl Lowy. **13**: 383—1942

Methods for measuring the performance of hearing aids. Frank F. Romanow. **13**: 294—1942

Relation of audiogram measurements to hearing aid characteristics based on commercial experience. Fred W. Kranz and Carl E. Rudiger. **13**: 363—1942

ABSTRACTS

Appeal to science for specialized hearing aids of true selective amplification. Matie E. Winston. **13**: 335—1942

Basis for the prediction of performance of deaf aids. Charles M. R. Balbi. **13**: 335—1942

Hearing aids. Fred W. Kranz (book review). **13**: 322—1942

Hearing aids: uniform and selective: monaural, diotic and binaural; air and bone conduction. Norman A. Watson. **13**: 335—1942

Relation of audiogram measurements to hearing-aid characteristics based on commercial experience. F. W. Kranz and C. E. Rudiger. **13**: 335—1942

Some considerations relative to the calibration of bone-conduction receivers for audiometers. L. A. Watson. **13**: 336—1942

PATENTS

Acoustic device. **13**: 400—1942
Audiometer. **13**: 327—1942
Auditory masking method. **13**: 77—1941
Bone conduction audiphone. **13**: 400—1942
Bone conduction hearing device. **13**: 76—1941
Bone telephone receiver. **13**: 401—1942
Custom-made hearing aid receiver tip. **13**: 199—1941
Ear protector. **13**: 401—1942
Ear stopper. **13**: 199—1941
Hearing aid. **13**: 198—1941
Hearing aid amplifier. **13**: 327—1942
Hearing aid device. **13**: 401—1942
Method for tseting bone conduction. **13**: 76—1941
Wearable bond-conduction hearing aid. **13**: 199—1941

4.7 Masking

SUBTITLES

Masking and spectrum levels for average room noise. Harvey Fletcher. **13**: 91—1941

Threshold hearing level curves for quiet and noisy rooms. Harvey Fletcher. **13**: 91—1941

4.9 Pitch

SUBTITLE

Duration thresholds for pitch perception. W. Türk. **13**: 66—1941

4.10 Subjective Tones

PAPER

Effect of middle ear pressure upon distortion. Ernest Glen Wever, Charles W. Bray and Merle Lawrence. **13**: 182—1941

ABSTRACTS

Contribution offered towards a discussion of the paper "Pitch and the missing fundamental." William Braid White. **13**: 87—1941

Pitch and the missing fundamental. Don Lewis **13**: 84—1941

5. Applied Acoustics, Instruments and Apparatus

5.1 General, Unclassified

ABSTRACTS

Acoustic experiments with an electronic switch. S. K. Wolf. **13**: 332—1942

Apparatus for the direct measurement of force-displacement characteristics of mechanical systems at audio-frequencies. J. R. Haynes. **13**: 332—1942

Steady circulations in the Kundt's tube. K. Schuster and W. Matz (Akustische Zeits. **5**, 349–352 (1940)). **13**: 320—1942

PATENTS

Acoustic apparatus. **13**: 401—1942
Acoustical projectile. **13**: 199—1941
Noise making tube. **13**: 327—1942

5.3 Acoustical Impedance Measurement (see also 11.4)

PAPERS

Acoustic wattmeter, an instrument for measuring sound energy flow. C. W. Clapp and F. A. Firestone. **13**: 124—1941

Continuously variable acoustic impedance. Edward C. Jordan. **13**: 8—1941

5.4 Analyzers and Filters. Acoustic Filters. Oscillographs (see also 5.15)

PAPERS

Acoustic filtration by membranes. L. W. Labaw. **13**: 353–1942

Acoustic filtration in parallel conduit structures. L. W. Labaw. **13**: 345—1942

Analyzer for sub-audible frequencies. H. H. Scott. **13**: 360—1942

ABSTRACTS

Acoustic filtration by membranes. Louis W. Labaw. **13**: 333—1942

Analyzer for sub-audible frequencies. H. H. Scott. **13**: 334—1942

PATENT

Receiver cap acoustic filter. **13**: 202—1941

5.5 Audiometers

PATENTS

Audiometer. **13**: 77—1941; 327—1942

5.51 Broadcasting

PAPER

Performance of broadcast studios designed with convex surfaces of plywood. C. P. Boner. **13**: 244—1942

ABSTRACT

Contemporary problems in television sound. C. L. Townsend. **13**: 334—1942

5.7 Frequency Standards. Frequency Measuring and Recording Instruments

ABSTRACT

Demonstration of the chromatic stroboscope as a general purpose frequency meter. O. H. Schuck and R. W. Young. **13**: 82—1941

PATENTS

Acoustic device. **13**: 400—1942
Bone conduction audiphone. **13**: 400—1942
Stethoscope. **13**: 401—1942
Vibratory frequency standard. **13**: 401, 402—1942
Visual tip for vibrating indicators. **13**: 401—1942

5.8 Loudspeakers, Horns (see also 5.13 and 5.17)

PAPERS

Low frequency horn of small dimensions. Paul W. Klipsch. **13**: 137—1942

Theory of conical sound radiators. W. N. Brown, Jr. **13**: 20—1941

SUBTITLE

Phase and delay characteristic of metal diaphragm direct radiator loudspeaker. Francis M. Wiener. **13**: 122—1941

ABSTRACT

System concept of electroacoustical systems. Hugh S. Knowles. **13**: 81—1941

PATENTS

Loudspeaker. **13**: 402—1942
Sound reproducing system. **13**: 402—1942

5.9 Microphones, Vibration Microphones, and Microphone Calibration Equipment

PAPERS

Analyzer for sub-audible frequencies. H. H. Scott. **13**: 360—1942

General purpose vibration meter. H. H. Scott. **13**: 46—1941

Phase distortion in electroacoustic systems. Francis M. Wiener. **13**: 115—1941

Uniphase unidirectional microphones. Benjamin B. Bauer. **13**: 41—1941

SUBTITLES

Phase distortion in microphones. Francis M. Wiener. **13**: 115—1941

Pressure calibration of miniature condenser microphones W. E. D96436 and W. E. 640. Francis M. Wiener. **13**: 117—1941

Reciprocity calibration of miniature condenser microphone in free space. Francis M. Wiener. **13**: 119—1941

ABSTRACTS

Absolute calibration of microphones. Guy S. Cook and Richard K. Cook. **13**: 81—1941

Apparatus for the direct measurement of force-displacement characteristics of mechanical systems at audiofrequencies. J. R. Haynes. **13**: 332—1942

General purpose vibration meter. H. H. Scott. **13**: 82—1941

Phase distortion in electroacoustical systems. Francis M. Wiener. **13**: 81—1941

PATENTS

Contact microphone. **13**: 403—1942

Electroacoustical apparatus. **13**: 200—1941

Microphone. **13**: 403—1942

Sound translating apparatus. **13**: 403—1942

Vibration measuring and recording apparatus. **13**: 200—1941

Vibration meter. **13**: 403—1942

5.10 Navigational Instruments. Depth and Altitude Finding Instruments. Geophysical Prospecting. Under-Water Sound. Submarine Detectors

PATENTS

Apparatus for and method of seismograph recording. **13**: 404—1942

Echo sounding apparatus. **13**: 404—1942

Geophysical instrument. **13**: 404—1942

Light and sound signaling system. **13**: 405—1942

Listening helmet for sound locators. **13**: 200—1941

Measurement of sound velocities in strata traversed by boreholes. **13**: 200—1941

Method and apparatus for recording waves. **13**: 328—1942

Method and apparatus for translating seismic waves. **13**: 404—1942

Method of geophysical investigation. **13**: 403—1942

Method of seismic surveying. **13**: 403—1942

Prospecting method and apparatus. **13**: 404—1942

Seismic exploration method. **13**: 404—1942

Seismic surveying. **13**: 328—1942

Seismograph prospecting apparatus. **13**: 404—1942

Sound direction indicator. **13**: 404—1942

5.15 Sound Level Meters. Level Recorders. Sound Pressure Measurement (see also 5.4 and 7.1)

PAPERS

Acoustic wattmeter, an instrument for measuring sound energy flow. C. W. Clapp and F. A. Firestone. **13**: 124—1941

General purpose vibration meter. H. H. Scott. **13**: 46—1941

Sound measurement room utilizing the live end-dead end studio principle. M. D. Stahl and W. C. Louden. **13**, 9—1941

ABSTRACT

General purpose vibration meter. H. H. Scott. **13**: 82—1941

PATENTS

Noise level indicator. **13**: 405—1942

Sound intensity recorder. **13**: 77—1941

5.16 Sound Recording and Reproducing (see also 5.13)

PAPERS

Correlation between elastic deformation and vertical forces in lateral recording. S. J. Begun and T. E. Lynch. **13**: 284—1942; Erratum. **13**, 392—1942

Large radius stylus for the reproduction of lateral cut phonograph records. John D. Reid. **13**: 274—1942

Mechanical and optical equipment for the stereophonic sound film system. E. C. Wente, R. Biddulph, L. A. Elmer and A. B. Anderson. **13**: 100—1941

Noise and wear reducing phonograph reproducer with controlled response. F. H. Goldsmith. **13**: 281—1942

Properties of the dulled lacquer cutting stylus. C. J. LeBel. **13**: 265—1942

Stereophonic sound film system—general theory. Harvey Fletcher. **13**: 89—1941

Stereophonic sound film system—pre- and post-equalization of compandor systems. John C. Steinberg. **13**: 107—1941

Tracing distortion in the reproduction of constant amplitude recordings. Ludwig W. Sepmeyer. **13**: 276—1942

ABSTRACTS

Automatic record changers and recorders. John F. Rider (book review). **13**: 395—1942

Discussion of several factors contributing to good recording. R. A. Lynn. **13**: 331—1942

Electrical equipment for the stereophonic sound-film system. W. B. Snow and A. R. Soffel. **13**: 86—1941

Errors in light band width measurements on phonograph records. Richard Bierl (Akustische Zeits. **5**, 145–147 (1940)). **13**: 190—1941

High fidelity from the musician's viewpoint. Wilmer T. Bartholomew. **13**: 331—1942

High fidelity from the musician's viewpoint. Ernest La Prade. **13**: 331—1942

Influence of elastic properties of disk material upon the "pinch-effect" in lateral recording. S. J. Begun and T. E. Lynch. **13**: 330—1942

Internally damped rollers. E. C. Wente and A. H. Müller. **13**: 86—1941

Large radius stylus for the reproduction of lateral cut phonograph records. John D. Reid. **13**: 330—1942

Light valve for the stereophonic sound-film system. E. C. Wente and R. Biddulph. **13**: 86—1941

Mechanical and optical equipment for the stereophonic sound-film system. E. C. Wente, R. Biddulph, L. A. Elmer and A. B. Anderson. **13**: 85—1941

Noise and wear reducing phonograph reproducer with controlled response. F. H. Goldsmith. **13**: 330—1942

Non-cinching film-rewind machine. L. A. Elmer. **13**: 86—1941

Phonograph pick-up of the moving coil type. Theodore Lindenberg, Jr. **13**: 330—1942

Physik und Technik des Tonfilms (Physics and technique of sound films). Hugo Lichte and Albert Narath (book review). **13**: 321—1942

Properties of the dulled lacquer cutting stylus. C. J. LeBel. **13**: 330—1942

Recording laboratory in the Library of Congress. Jerome B. Wiesner. **13**: 331—1942

Stereophonic sound-film system—general theory. Harvey Fletcher. **13**: 85—1941

Stereophonic sound-film system—pre-and post-equilization of compandor systems. J. C. Steinberg. **13**: 86—1941

Tracing distortion in the reproduction of constant amplitude recordings. Ludwig W. Sepmeyer. **13**: 80—1941

PATENTS

Cabinet for housing sound-reproducing apparatus. **13**: 201—1941

Cabinet for phonographs. **13**: 201—1941

Device for producing articulate sounds. **13**: 406—1942

Device for the production of sound vibrations of definite frequency by means of a pipe or whistle. **13**: 77—1941

Magnetic sound recording device. **13**: 405—1942

Sound apparatus. **13**: 328—1942

Sound characteristic control. **13**: 405—1942

Sound record. **13**: 201—1941

Sound recording device. **13**: 405—1942

Vibration record and method of making the same. **13**: 405—1942

5.17 Telephone Receivers (see also 5.8)

PATENTS

Receiver cap acoustic filter. **13**: 202—1941

Voice silencer. **13**: 201—1941

5.19 Tuning Forks

PATENT

Tuning fork. **13**: 202—1941

6. Musical Instruments and Music

6.1 General, Unclassified

PAPER

Musical theory in retrospect. Llewlyn S. Lloyd. **13**: 56—1941

ABSTRACT

Musical acoustics. Charles C. Culver (book review). **13**: 322—1942

PATENTS

Musical instrument. **13**: 328—1942

Musical string. **13**: 202—1941

6.2 Bells

PATENTS

Electric carillon. **13**: 406—1942

Electrical musical instrument for producing bell tones. **13**: 406—1942

6.3 Brass

PAPERS

Directivity and the acoustic spectra of brass wind instruments. Daniel W. Martin. **13**: 309—1942

Lip vibrations in a cornet mouthpiece. Daniel W. Martin. **13**: 305—1942

Resonance characteristics of a cornet. J. G. Woodward. **13**: 156—1941

Vibration of the walls of a cornet. H. P. Knauss and W. J. Yeager. **13**: 160—1941

SUBTITLES

Sound pressure *vs.* azimuth angle for cornet. Daniel W. Martin. **13**: 310—1942

Sound pressure *vs.* azimuth angle for French horn. Daniel W. Martin. **13**: 310—1942

ABSTRACTS

Directivity and the acoustic spectra of brass wind instruments. Daniel W. Martin. **13**: 333—1942

Lip vibrations in a cornet mouthpiece. Daniel W. Martin. **13**: 80—1941

Some characteristics of the tuning of valved wind instruments. Robert W. Young. **13**: 333—1942

PATENTS

Musical instrument. **13**: 77—1941

Piston valve for musical wind instruments. **13**: 406—1942

6.4 Drums and Traps

PATENTS

Apparatus and method for tuning. **13**: 329—1942

Kettle drum tuning mechanism or tympano. **13**: 406—1942

6.5 Organs (see also 6.9)

PAPERS

Harmonic relations in the partials of organ pipes and of vibrating strings. A. W. Nolle and C. P. Boner. **13**: 145—1941

Initial transients of organ pipes. A. W. Nolle and C. P. Boner. **13**: 149—1941

ABSTRACTS

Some aspects of the transient and steady state tones of organ pipes and of vibrating strings. A. W. Nolle and C. P. Boner. **13**: 333—1942

Tone spectrum of a Silbermann organ. W. Lottermosser (Akustische Zeits. **5**, 324–330 (1940)). **13**: 189—1941

PATENTS

Control for electrically operated pipe organ. **13**: 406—1942

Electrical organ. **13**: 78—1941

Musical instrument. **13**: 406—1942

6.6 Pianos

PATENTS

Electric piano. **13**: 407—1942

Electric piano construction. **13**: 407—1942
Key action for musical instruments. **13**: 407—1942
Keyboard for electrical musical instruments. **13**: 406—1942
Mechanism for pianos. **13**: 202—1941
Piano action. **13**: 202—1941; 407, 408—1942
Piano key and action connection. **13**: 408—1942
Piano structure. **13**: 407—1942
Producing harmonic tones in pianos. **13**: 408—1942
Sounding board for pianos. **13**: 78—1941
Transposing keyboard for pianos and accordions. **13**: 329—1942
Tuning fork piano. **13**: 408—1942

6.7 Violin Family

PAPERS

Harmonic relations in the partials of organ pipes and of vibrating strings. A. W. Nolle and C. P. Boner. **13**: 145—1941
Physical properties of wood for violin construction. R. B. Abbott and G. H. Purcell. **13**: 54—1941

PATENTS

Bow for musical stringed instruments. **13**: 408—1942
Musical instrument. **13**: 408—1942
Tuning device for string instruments. **13**: 408—1942

6.9 Electronic Musical Instruments (see also 6.5)

PATENTS

Electrical musical instrument. **13**: 78, 203—1941; 329, 409—1942
Electrical organ. **13**: 78—1941
Electric music instrument. **13**: 78—1941
Electronic musical instrument. **13**: 203—1941
Musical instrument. **13**: 203, 204—1941; 409—1942
Sound amplification method and device. **13**: 203—1941

7. Noise

7.4 City Noise

PAPERS

Acoustical Society and noise abatement. Paul E. Sabine. **13**: 207—1942
Bibliography on noise. P. E. Sabine. **13**: 210—1942
City noise. Shirley W. Wynne. **13**: 214—1942
Industrial noises and industrial deafness. Walter A. Rosenblith. **13**: 220—1942
Report of activities of the National Noise Abatement Council. George P. Little and F. Edgar McGee. **13**: 211—1942
What can the hospital do about noise? Charles F. Neergaard. **13**: 217—1942

ABSTRACTS

Acoustical Society and noise abatement. Paul E. Sabine. **13**: 332—1942
City noise. Shirley W. Wynne. **13**: 331—1942
Effect of high intensity noise levels on surrounding areas. J. S. Parkinson. **13**: 332—1942
Greater Chicago noise survey. H. A. Leedy. **13**: 332—1942
History of noise abatement in New York City. Ernest H. Peabody. **13**: 332—1942
Report of activities of the national noise abatement council. George P. Little and F. Edgar McGee. **13**: 331—1942

7.6 Noise in Buildings

PAPER

What can the hospital do about noise? Charles F. Neergaard. **13**: 217—1942

ABSTRACT

What can the hospital do about noise? Charles F. Neergaard. **13**: 332—1942

PATENT

Acoustic material. **13**: 197—1941

7.7 Machinery Noise

PAPERS

Ball bearing noise and vibration. Walter T. Buhl. **13**: 51—1941
Sound measurement room utilizing the live end-dead end studio principle. M. D. Stahl and W. C. Louden. **13**: 9—1941

ABSTRACT

Effect of high intensity noise levels on surrounding areas. J. S. Parkinson. **13**: 332—1942

PATENTS

Apparatus for silencing pulsating gases. **13**: 204—1941
Device for destroying sound waves more especially utilizable as a silencer for combustion and explosion engines. **13**: 79—1941
Exhaust silencer. **13**: 329—1942
Method of making mufflers. **13**: 410—1942
Muffler. **13**: 78, 204—1941; 409, 410—1942
Muffler and silencer construction. **13**: 204—1941
Muffler construction. **13**: 79—1941
Pipe line noise eliminator. **13**: 409—1942
Silencer. **13**: 78, 204—1941; 410—1942
Silencer construction. **13**: 204—1941; 409—1942
Silencer for internal combusion engines. **13**: 78—1941
Silencer for rock drills. **13**: 204—1941
Silencing device. **13**: 410—1942
Spark arrester silencer. **13**: 410—1942
Suction muffler. **13**: 78—1941

8. Standards

8.1 General, Unclassified

ABSTRACT

Dictionary of radio and television terms. Ralph Stranger (book review). **13**: 395—1942

9. Speech and Singing

9.1 General, Unclassified

PAPER

Method of measuring the percentage of capacity for hearing speech. Edmund Prince Fowler. **13**: 373—1942

ABSTRACT

Voice, its production and reproduction. Douglas Stanley and J. P. Maxfield (book review). **13**: 70—1941

9.6 Instruments Relating to Speech and Singing

PATENT

System for the artificial production of vocal or other sounds. **13**: 204—1941

10. Supersonics (Ultrasonics)

10.1 General, Unclassified

ABSTRACT

Grundlagen und Ergebnisse der Ultraschallforschung. Egon Hiedemann (book review). **13**: 321—1942

10.3 Supersonic Instruments

PATENTS

Dog whistle. **13**: 205—1941

High frequency sound generator. **13**: 205—1941

10.4 Gases, Supersonic Velocities, Dispersion, and Absorption (see also 11.3)

PAPER

Temperature and frequency effects on ultrasonic velocities in carbon dioxide. C. J. Overbeck and H. C. Kendall. **13**: 26—1941

10.5 Liquids, Supersonic Velocities, Dispersion, and Absorption

PAPERS

Absorption of ultrasonic waves in highly viscous liquids. Joseph Lawrence Hunter. **13**: 36—1941

Origin of the absorption of ultrasonic waves in liquids. Karl F. Herzfeld. **13**: 33—1941

SUBTITLE

Absorption *versus* temperature for olive oil, glycerine, linseed oil, and castor oil. Joseph Lawrence Hunter. **13**: 38—1941

PATENT

Method of extracting constituents of living cells. **13**: 79—1941

10.8 Chemical Effects of Supersonic Waves

PATENTS

Breaking petroleum emulsions. **13**: 410—1942

Separation of phases with the aid of sonic waves. **13**: 410—1942

10.9 Biological Effects of Supersonic Waves

PATENT

Method of extracting constituents of living cells. **13**: 79—1941

11. Waves and Vibrations

11.3 Propagation of Sound. Absorption during Propagation. Velocity of Sound (see also 10.4)

PAPER

Velocity of sound in air. H. C. Hardy, D. Telfair and W. H. Pielemeier. **13**: 226—1942

ABSTRACT

Corrections on the measurements of the velocity of sound in gases. W. H. Pielemeier and H. C. Hardy. **13**: 80—1941

11.4 Radiation from Vibrating Objects. Acoustical Impedance. Mechanical Impedance (see also 5.3)

PAPERS

Heat conduction effects in sound emission. Ray S. Alleman. **13**: 23—1941

Theory of conical sound radiators. W. N. Brown, Jr. **13**: 20—1941

11.6 Sound Transmission Through Tubes

PAPERS

Acoustic filtration by membranes. L. W. Labaw. **13**: 353—1942

Acoustic filtration in parallel conduit structures. L. W. Labaw. **13**: 345—1942

ABSTRACT

Steady circulations in the Kundt's tube. K. Schuster and W. Matz (Akustische Zeits. **5**, 349–352 (1940)). **13**: 320—1942

11.7 Theory of Waves and Vibrating Systems

PAPERS

Frequency distribution of normal modes. Glenn M. Roe. **13**: 1—1941

Harmonic relations in the partials of organ pipes and of vibrating strings. A. W. Nolle and C. P. Boner. **13**: 145—1941

ABSTRACTS

Acoustic filtration by membranes. Louis W. Labaw. **13**: 333—1942

Duration thresholds for the perception of certain transient phenomena. W. Türk (Akustische Zeits. **5**, 129–145 (1940)). **13**: 65—1941

THE AMERICAN INSTITUTE OF PHYSICS

INCORPORATED

ADMINISTRATIVE STAFF

HENRY A. BARTON, *Director*

MADELINE M. MITCHELL, *Publications Manager*

JOHN T. TATE, *Adviser on Publications*

Office: 175 Fifth Avenue, New York, New York

JOURNALS

THE PHYSICAL REVIEW
REVIEWS OF MODERN PHYSICS
JOHN T. TATE, *Editor* (on leave)
J. W. BUCHTA, *Acting Editor*

JOURNAL OF THE OPTICAL SOCIETY OF AMERICA
GEORGE R. HARRISON, *Editor*

THE JOURNAL OF THE ACOUSTICAL SOCIETY OF AMERICA
FLOYD A. FIRESTONE, *Editor*

AMERICAN JOURNAL OF PHYSICS
(Formerly THE AMERICAN PHYSICS TEACHER)
DUANE ROLLER, *Editor*

THE REVIEW OF SCIENTIFIC INSTRUMENTS
GAYLORD P. HARNWELL, *Editor*

THE JOURNAL OF CHEMICAL PHYSICS
JOSEPH E. MAYER, *Editor*

JOURNAL OF APPLIED PHYSICS
ELMER HUTCHISSON, *Editor*

GOVERNING BOARD

[illegible]

The American Institute of Physics is a membership corporation of which five societies are the founding members. These five societies are the principal national societies devoted to pure and applied physics in America. Their names, and those of their representatives who form the Governing Board of the Institute, are given above. The principal work of the Institute is the publication of journals sponsored by the societies or by itself. The names and the editors of the journals are also listed above.

The broad purpose of the Institute is to promote, in all matters of which its present [illegible] or future members and societies [illegible] with the Founder Societies and the journals. It aims to advance the science and profession of physics and to promote cooperation between [illegible] the science and the industries. To achieve these aims, it is prepared in need of an endowment and is empowered by law to administer grants and [illegible] funds.

This number of THE JOURNAL OF THE ACOUSTICAL SOCIETY OF AMERICA
was issued April 9, 1942

LANCASTER PRESS, INC., LANCASTER, PA.